Labour Canada   Travail Canada

GRAIN INDUSTRY DUST EXPLOSIONS AND FIRES

OCCUPATIONAL SAFETY AND HEALTH

Canada

GRAIN INDUSTRY

DUST EXPLOSIONS AND FIRES

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PREFACE

This document discusses many factors associated with the causes and the prevention of grain dust explosions and fires. It is based on the experience of such accidents in 13 countries. The document is not intended to provide a detailed analysis of the data, but rather to provide a broad overview.

The concise presentation of data, charts and brief descriptions of the preventive measures and design features required to reduce the number of accidents will hopefully aid the grain industry in becoming more aware of the extent of the problem and the identification of control measures. The information is also prepared for reference purposes for individuals, unions and government agencies.

The contribution of the countries, Australia, Belgium, England, France, Germany (West), Japan, Netherlands, USSR, Sweden, U.S.A.; and Canadian Grain Commission and Canadian Western Grain Elevator Association is gratefully acknowledged.

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AN OVERVIEW OF DUST EXPLOSIONS AND FIRES IN THE GRAIN HANDLING INDUSTRY

1. INTRODUCTION

1.1 Background and Purpose of Study

Grain and flour dusts in suspension can form explosive clouds, and the dusts can ignite and propagate flame readily because the source of heat required is relatively small. In January 1980, in Montreal, a massive explosion ripped through eight silos and blew off the top of a 30-metre concrete grain elevator, killing one worker and injuring at least seven. The explosion tore off the top levels of the grain elevator, and rained debris down on a dozen railroad hoppers and boxcars parked on a nearby siding, causing extensive damage. It has been reported that sometimes the debris can travel in air as far as five kilometres. More recently, in April 1981, in Texas, one grain elevator exploded, killing three workers and injuring 33, when a series of explosions ripped through an elevator complex. Several hours later in Bellwood, Nebraska, a second grain elevator exploded, killing one worker and seriously injuring two others. Since the turn of the century, more than 1 100 explosions have occurred at grain handling facilities in the United States, killing nearly 500 people. Statistics on the dust explosions in the United States show that more than 50 per cent of all explosions of combustible dusts have occurred in grain elevators and flour mills. In Canada, statistics provided by the Canadian Grain Commission based on the claims for work injury compensation indicate that fires and explosions result in a work injury frequency rate ranking fourth or fifth among all federal departments and agencies, and indicate an increasing trend. Since 1976, in the United States, the number of explosions and fires in grain elevators has increased significantly. And yet, often the causes of these accidents have never been clearly identified even by experienced investigators.

The purpose of this document is to draw attention to certain important features of accidents by highlighting a variety of the statistics reported by the United States, several European countries and Japan; and to review their preventive programs. The Canadian milieu is reviewed in this context.

The countries and the number of explosions for different periods by the countries are as follows:

Table 1

Countries and Their Dust Explosion Cases

Countries	Cases (Explosion)
Australia	2
Belgium	1
Canada	40
England	5
France	1
Germany	10
Japan	23
Netherlands	59
Sweden	1
USSR	N/A
U.S.A.	465
TOTAL	607

Note that these figures are not the totals of all explosions that have actually happened but only of those reported to have happened. Explosions are grossly underreported due to lack of information, or due to inconsistent and decentralized reporting.

1.2 Methodology

The statistics have been synthesized, using a variety of source documents, the reports and letters from the countries to Labour Canada on their experiences and preventive measures and regulations regarding fire and the explosion. The number of cases of explosion used for statistical analysis is 579, as first reported by the countries, covering different periods of time, and 104 fire cases experienced by Western Canadian grain handling industries only over the period of 1970-1979. The number of fire accidents, however, does not account for all fires in the Canadian grain handling industries during the period.

1.3 Delimitation

The data collected in this report have definite limitations. They lack uniformity in defining certain variables between the countries. Particularly, information on the preventive measures and regulations used by the countries is not always available, and when available is not necessarily comprehensive.

1.4 General Review

As we shall notice in Table 2 there seems to be no significant difference between the countries with respect to the most frequently cited sources of ignition, types of industry, and the machines or parts

involved in the explosions. Historically, "Open Fire" was blamed most for the accidents during the period 1860-1900. After 1900 the most commonly cited cause was "Foreign Material". Since 1961, "Welding" and "Friction" have been reported most frequently as the causes. The machines and parts that were involved most often were "Grinding Apparatus" until 1960, and "Bucket Elevator" and "Hopper" after that. As to the industries, Canadian experience was almost congruent with the other countries, that is, "Storage", "Transhipment", "Compound Feed Mill", and "Flour Mill", in that order were the most common. Of the 33 types of material involved, milo, starch and flour were reported as being most susceptible to explosions. Japanese experience indicates that 30.4 per cent of the primary ignitions of the explosions induced fires.

Table 2

Major Primary Sources of Ignition,
Materials, Machines and Industries Involved in Explosion
(1860-1979)

Materials	Causes		Machines		Industries	
	Canada	Others*	Canada	Others*	Canada	Others*
milo	(No information available, 1860-1900)	open fire (1860-1900)	grinding apparatus	grinding apparatus	storage, transhipment	storage, transhipment
starch	foreign material (1901-1960)	foreign material (1901-1960)	hopper	bucket elevator	compound feed mill	compound feed mill
flour	friction (1961-1979)	welding (1961-1979)	elevator leg, bin mixer	hopper	flour mill	flour mill

*"Others" refers to those countries which communicated with Labour Canada.

1.5 Canadian Situation

As of August 1, 1977, licensed elevators in Canada numbered 3 821. Of the total, 3 739 were primaries, 25 terminals, 30 processes, and 27 transfers, with total estimated workers of 57 000. Since 1916 at least 40 incidents of dust explosions have been recorded in Canada. Canadian Western Grain Elevator Association reported that during the period of 1970-1979 there were 104 fires in the industries. The actual number may be higher since Canada has no well established registration of dust explosions or fires. What is available now are detailed reports of explosions resulting in injury and extensive property damage, but records of less significant incidents are incomplete. Records of insurance loss and of fires are available from insurance companies, inspection agencies, and provincial grain elevator associations. But these records do not provide sufficient details to determine the causes of primary sources of ignition or explosions or of fires, machines and parts, and materials

involved in the incidents. As mentioned earlier, there are no significant differences between Canada's experience and the experience of the other countries reporting in the causes, machines and parts, or types of industry involved in explosions. Mechanical failures, arson, lightning and open fire appear to be the main causes of fires (Table 3). Most of the fires (80.8 per cent) occurred outside working hours (Table 10).

The preventive measures taken or suggested by the countries and their design features are summarized as follows:

1.6 Preventive Measures for Explosions and Fires

- Good housekeeping practices should be observed;

- No machinery should be started without first starting the dust extractor;

- No dust should be allowed to return to the grain stream;

- Floors should be sloped so that trucks can roll out without having to start engines;

- No shelled corn should be put into a storage elevator before cleaning;

- Air humidity should be maintained at as high a level as is compatible with the preservation and handling processes;

- No lamp should be located in, or lowered down into, the hopper;

- No open fire or smoking should be permitted;

- Friction should be minimized; e.g., bearings ought to be lubricated with the prescribed grease;

- Axles of the various machines ought to be aligned correctly;

- Ropes should be made of anti-static material;

- Conveyor screws and chain transporters should not operate in unloaded condition;

- A slippage indicator should be attached to bucket elevators;

- Mechanical spark and static electricity should be controlled;

- Magnetic or electromagnetic separators of steel objects should be used to control foreign material in the first row of roller, hammer or other milling;

- There should be a dust filter exhaust system;

- Driers should always be monitored through use of automatic temperature regulators or thermostats that automatically cut off the heat supply;

- It is necessary to have an effective ventilation system;

- All sources of light ought to be dust-tight;

- All electric installations should be kept dust-free by housing them in dust-tight devices;

- Power-operated tools must not be used in a dusty environment;

- Water should be kept out of the silo top, to eliminate the hazard of pipes bursting in the winter;

- Personnel should be present throughout the relevant parts of the terminal when conveyors and machinery are running;

- Compressed air should only be used to blow down dust when there is no other feasible means of removing that dust;

- Dust should be put in bins placed outside of the processing rooms and silo bins;

- Investigation of explosions has revealed that the more elevator volumes connected, the more destruction may occur. For this reason, the division of existing elevator volumes into a number of isolated volumes may be necessary;

- Dust accumulations should be minimized by the use of smooth-surfaced walls and floors;

- The use of aluminum, magnesium and similar light metal paints should be avoided in the elevator;

- Metal objects should never be lowered into bins;

- Battery-operated lamps, instead of electrical lamps on leads, should be used for inspecting bins;

- Proper alignment and maintenance of belt drives must be assured; V-belts should be avoided where possible;

- Proper fire extinguishers, automatic detectors, alarm systems and sprinkler installations should be present;

- When a dust cloud becomes ignited, the flame initially moves relatively slowly, and the incipient rise in pressure can be detected rapidly. At this point, suppression agent should automatically be injected into the volume to quench the flame;

- There should be a means of localizing explosions in the smallest possible volume of the building with the aim of preventing explosion propagation;

- Sieve separators should be used for detecting grain;

- To minimize repair work inside elevator buildings, facilities should be provided for disassembling of bearing members, spouts, and protective casings.

1.7 Design Features

- Elevator legs must be constructed of non-combustible material, dust-tight, provided with sample inspection and maintenance access, and driven by individual motors, and drives of optimum size

- All machines must have individual connections to the power source and must not run idle

- Dust collection systems must be installed at all dust producing points

- Machines and conveyors must be grounded

- The cover of the hopper should be constructed from as lightweight material as possible, as should be the roof over it. If a dust explosion occurs, the cover and possibly the roof can then be flung off and away

- Mount dry filters with housings in a separate room. This room ought to be constructed in such a way that in the event of an explosion, the outer wall can be flung away and the explosion can not move through the machinery building

- Automatic valves should be arranged in the openings of fire proof walls

- Conveyor and elevator drive pulleys are rubber lagged

- Laggings are vulcanized to the pulley and provided with chevron grooving

- A special responsive switch should be connected to a pulley driven by the belt thus detecting any appreciable slippage of conveyor belts on drive pulleys

- Vulcanizing is adopted instead of metal belt joiners

- Statutory requirements for building, machinery, safety and electrical installation are applied for construction of grain silos and terminals

- Non-flammable materials are used for building enclosures and galleries in grain handling areas, and these enclosures and galleries should be designed for pressure relief, venting with light wall cladding panels which would blow out in the unlikely event of an explosion

Table 3

Reported Causes of Explosions and Fires*

Causes	Explosions (1860-1979)		Fires (1970-1979)	
	Frequency	%	Frequency	%
Unknown	259	44.7	24	23.1
Foreign Material	94	16.2	-	-
Mechanical	-	0	16	15.4
Friction or Plug up	47	8.1	6	5.8
Arson	-	-	15	14.4
Welding	42	7.3	1	1.0
Open Fire or Smoking	26	4.5	12	11.5
Electric Spark	23	4.0	-	-
High Temperature	20	3.5	-	-
Mechanical Spark	18	3.1	-	-
Fire	17	2.9	-	-
Spontaneous Heat	11	1.9	3	2.9
Static Electricity	9	1.6	8	7.7
Trespassers	-	-	2	1.9
Heating Equipment	-	-	2	1.9
Lamp	9	1.6	-	-
Lightning	4	0.7	14	13.5
During Cut-off	-	-	1	1.0
TOTAL	579**		104	

*Based on Report No. 2 of the Fire and Explosion Task Force, Western Grain Elevator Association, Western Primary Elevator, November 1980, 759-167 Lombard Ave., Winnipeg, Manitoba.

**Some cases were not included due to lack of information.

Table 4

Types of Industry Involved in Explosions,
All Countries Reporting
(1860–1979)

Industries	1860–1900	1901–1910	1911–1920	1921–1930	1931–1940	1941–1950	1951–1960	1961–1970	1971–1979	N/A	Total
N/A							1	12	18	2	33
Flour Mill	18	16	25	15	9	16	4	3	1	7	114
Storage, Transhipment	2	5	26	43	62	40	19	1	6		204
Compound Feed Mill		9	16	37	22	20	21	16	12	2	155
Starch Factory	2	11	8	7	5	5	14	2	2	6	62
Seeds and Pulses					1	4	1				6
Sugar Mill							2	1			3
Soya Mill							1				1
Brewery									1		1
TOTAL	22	41	75	102	99	85	63	35	40	17	579

Table 5

Reported Causes by Years, All Countries Reporting
(1860-1979)

Causes	1860-1900	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1979	N/A	Total
Unknown	3	25	42	58	39	51	24	8	9	1	260
Welding					1	1	6	15	11	8	42
Lamp			1	1	2		1	2	1	1	9
Open Fire	15	1	6	1	1	1				1	26
Mechanical Spark	1	1	4	2	4	2	2	2			18
Fire	1		1	3	4	4	2			1	16
Lightning	1			2					1		4
Friction	1	3	8	5	11	4	2	5	8		47
Foreign Material		10	7	22	32	8	13			2	94
High Temperature		1		3	1	7	6	1		1	20
Electric Spark			4	5	3	3	3	2	2	1	23
Static Electricity			2		1	4	4		1	1	13
Spontaneous Heat									7		7
TOTAL	22	41	75	102	99	85	63	35	40	17	579

Table 6

Machines or Parts at Primary Ignition
(1860-1979)

Machines or Parts	1860-1900	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1979	N/A	Total	Per Cent of Total
Lighting	13		2	2		2					19	3.3
Grinding Apparatus	2	8	13	15	13	7	9	4	1	3	75	13.0
Bucket Elevator		2	6	2	8	1	6	9	5	3	42	7.3
Hopper		2	1	1	3	6	9	4	5	4	35	6.0
Conveyor Screw		2	1	3				1	3	1	11	1.9
Drier		1		3		2	6	2	3	1	18	3.1
Ventilator			1	1	2	2	2				8	1.4
Electric Installation			1	1		2	2	1		1	8	1.4
Peeler				1							1	0.2
Mixer				1		1	2		2	2	8	1.4
Electrometer				1					1		2	0.3
Converter					1						1	0.2
Dust Filter					1	4		3	2		10	1.7
Cleaner					1						1	0.2
Rheostat					1						1	0.2
Electric Motor						3					3	0.5
Welding Rectifier						1					1	0.2
Oilburner						1					1	0.2
Cyclone						1				1	2	0.3
Silo							1				1	0.2
Toaster							1				1	0.2

Table 6 (continued)

Machines or Parts	1860-1900	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1979	N/A	Total	Per Cent of Total
Bearing							1				1	0.2
Spout								1	1		2	0.3
Extraction								1			1	0.2
Chute								1	1	1	3	0.5
Bin								1	5		6	1.0
Receiving Leg									1		1	0.2
Elevator Leg									2		2	0.3
Unknown	7	26	50	71	69	52	24	7	8		314	54.2
TOTAL	22	41	75	102	99	85	63	35	40	17	579	

Table 7

Materials Handled When Explosions Occurred
(1860-1979)

Material	Frequency	Percent
Unknown	470	81.2
Flour	9	1.6
Barley	2	0.3
Compound Feed	3	0.5
Oats	3	0.5
Sugar	3	0.5
Gelatinized Starch	1	0.2
Cotton Seed	1	0.2
Maize	5	0.9
Milk Powder	2	0.3
Antioxidant	1	0.2
Starch	11	1.9
Dextrin	1	0.2
Maize Gluten	1	0.2
Rye	1	0.2
Milk Replacer	1	0.2
Wheat	4	0.7
Soya Beans	3	0.5
Wheat Offals	1	0.2
Maize Oil Flour	2	0.3
Ground Nuts	2	0.3
Beans, Peas	2	0.3
Cottonseed Flour	1	0.2

Table 7 (continued)

Material	Frequency	Percent
Linseed Flour	5	0.9
Rice Grinding Dust	1	0.2
Pet Food	1	0.2
Soya Bean Expellers	5	0.9
Pig Feed	1	0.2
Malt Expellers	1	0.2
Sunflower	4	0.7
Feed Grain	1	0.2
Copra	3	0.5
Corn	1	0.2
Milo	26	4.5
TOTAL	579	

CHART 1

CAUSES
OF
EXPLOSIONS AND FIRES

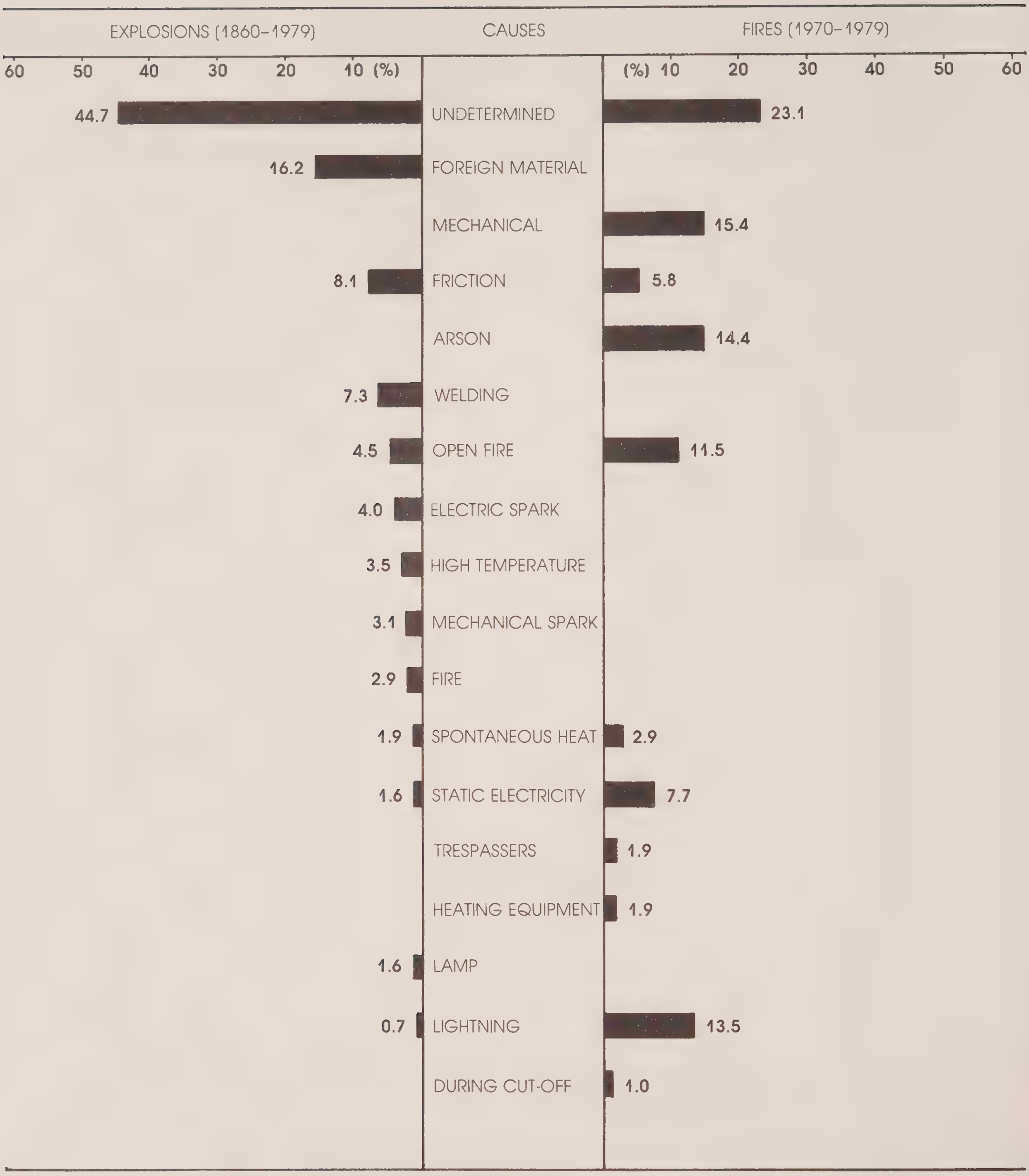


Table 8

Western Canadian Primary Elevator Fires and Reported Causes[1]
(1970-1979)

Year	Mechanical	Plug-up or Friction	Arson	Welding	Exposure to Open Fire or Smoking*	Spontaneous Combustion	Static Electricity	Trespassers	Heating Equipment	Lightning
1970			2				1			1
1971		1	2		1		1			1
1972	1	2	2		1		1			1
1973	4	1	1		1			1		3
1974	2	1	2			1	1		1	1
1975		1					1		1	2
1976	3		3		2			1		3
1977	2		3		2	1	1			
1978	2				4*	1				
1979	2			1	1		2			2
TOTAL	16	6	15	1	12	3	8	2	2	14

[1]Source: Western Grain Elevator Association, Western Primary Elevator, Fire and Explosion Task Force, Report No. 2 November, 1980.

*Includes Careless Smoking.

Table 9

Ten-Year Fire Loss Experience*

	Number of Losses	%
Time of Loss		
Office Hours (8:00 a.m.-5:00 p.m.)	14	13.5
After Hours	84	80.8
Unknown	6	5.8
TOTAL	104	
Age of Operator--Years		
18-25	12	11.5
26-35	22	21.2
36-45	10	9.6
46-55	19	18.3
55-up	10	9.6
Unknown	31	29.8
TOTAL	104	
Experience of Operators--Years		
0-5	23	22.1
6-10	17	16.4
11-15	6	5.8
16-20	10	9.6
20-up	18	17.3
Unknown	30	28.9
TOTAL	104	

*Based on Report No. 2 of the Fire and Explosion Task Force, Western Grain Elevator Association, Western Primary Elevator, November 1980, 759-167 Lombard Ave., Winnipeg, Manitoba.

2. GRAIN DUST EXPLOSION AND FIRE EXPERIENCES AND PREVENTIVE MEASURES, DESIGN FEATURES AND REGULATIONS REPORTED BY THE COUNTRIES

In the following pages the letters and reports from the countries are summarized in alphabetical order.

2.1 AUSTRALIA

There were about 21 port terminals and 930 country silos in 1978.

A. <u>Accidents</u>

Since 1918 there have been no more than six fires and only two explosions of note at small country installations. Maintenance staff attempted to clear quickly a grain choke in an elevator boot at one installation and used oxyacetylene equipment. It was believed that the dust inside the elevator exploded. The maintenance staff were burned and the elevator was damaged.

At the second country installation contractors were seal welding an elevator casing. It was believed that dust residue inside the casing exploded. The contract personnel were not injured.

B. <u>Causes</u>

Actual causes of the explosions reported:

- use of oxyacetylene equipment,
- welding.

Potential major causes of explosions reported:

- ignition source,
- low humidity,
- bad housekeeping with dust lying about the plant,
- flammable dust in air at or above the lower explosive limit,
- metal cutting.

C. <u>Preventive Measures</u>

The abiding concern of the Australian bulk grain handling authorities is to ensure the maximum of cleanliness. It is perhaps worth noting that all installations are washed down every year. Strict requirements are enforced for continual removal of surface dust from storages. They believe that this practice contributes very significantly to prevention of a build up of dust.

Some of their preventive measures are as follows:

- good housekeeping as mentioned above;
- dust is never returned to the grain stream;

- dust extraction, collector and dust plant;
- a fundamental feature of the grain conveying system within most Australian grain terminals is that the machinery cannot be started until the dust extraction system is operating;
- in the newer dust houses the floors have been sloped so that trucks can roll out of the facility without having to start their engines.

D. Designed Safety Features

- All conveyor and elevator drive pulleys are rubber lagged. In the case of the conveyors, the lagging is vulcanized to the pulley and provided with chevron grooving.

- The belt movement in grain terminals is monitored by a special response switch connected to a pulley driven by the belt, thus detecting any appreciable slippage of the main drive pulley. The slippage of conveyor belts on drive pulleys has been frequently cited as a contributing factor in grain dust explosions.

- Where splicing of conveyor belts is necessary, vulcanizing is adopted. The other alternative, the use of metal belt joiners, is avoided because metal belt joiners cause sparks through contact with the idlers.

- Construction of grain silos and terminals is to comply with all statutory requirements for building, machinery, safety and electrical installation.

- Building enclosures and galleries in grain handling areas are invariably constructed of non-flammable materials and designed for pressure relief, venting with light wall cladding panels which would blow out in the unlikely event of an explosion.

E. Operating Practices

- Invariably ensure that some personnel are present throughout the relevant parts of the terminal when conveyors and machinery are running because neither terminals nor country silos are fitted with heat sensing devices to detect friction where slipping of belts occurs or overheating of bearings in elevators and conveyors.

- Compressed air should be used to blow down dust only when there is no other feasible means of removing the dust.

- No smoking.

F. Maintenance Activities

- Welding, soldering and cutting are strictly forbidden without prior advice to, and permission from, the Terminal or Silo (Elevator) Superintendent. The area where the work is to be carried out is thoroughly cleaned and damped down and an asbestos blanket and wet sacking are placed around below the location of the cut or weld. Welding or cutting is not performed if work for the day will cease within two hours.

- Regularly test the level of dust in and around bulk grain shipping terminals and major country silos.

G. Static Electricity Control

Static electricity, which is often regarded as one of the causes of dust explosions, arises because of the transfer of a static charge to isolated metallic conductors which are not grounded. However, for static electricity to pose a problem, four conditions must exist:

1. An effective means of static generation;

2. A means of accumulating separate charges and maintaining a suitable difference of electrical potential;

3. A spark discharge of adequate energy;

4. A spark must occur in an ignitable mixture.

Before a dangerous arc can occur, the static electricity must reach the required minimum voltage, which depends on the conditions prevailing at the time and is usually around 30 000 volts.

Charges are detected by the utilization of a nuclear source (H3 "Tritium"), a high resistance measuring element and /m703 Static Meter Gum. The voltage read on the unit is the potential difference between the object under test, and the tip of the meter with reference to ground, providing the operator is grounded.

The reading indicates both the voltage level and the polarity of the charged surface.

H. Safety Officers and Safety Committees

- Each of the bulk handling authorities in Australia employs a safety officer. In most cases, these officers are engaged completely in safety duties, and in providing safe working conditions as well as in the avoidance of grain dust explosions.

- These officers have all received formal training in safety.

- Safety Committee meets regularly and safety officer obtains a copy of the minutes of their meeting. The non-receipt of minutes of meetings is often a sign that the committee has become inactive.

I. Interchange of Information

In Australia, there has always been a considerable interchange of information between the bulk grain handling authorities in the various states on matters relating to safety. Recently, this spirit of co-operation was made even more manifest when the authorities jointly prepared a manual of codes of practice and safe operation procedures. This arose as a result of a request by a trade union for legislation on a number of safety measures. The bulk grain handling authorities were not in favour of legislation being imposed on the industry from without and were able to persuade the union to accept production of the manual as a compromise.

J. Fire Suppression

While heat sensing devices are generally not installed in the grain terminals, consideration has been given to using CO_2 gas as an extinguisher. As well as its extinguishing capabilities, CO_2 possesses cooling effects, and is inexpensive and easy to acquire.

2.2 BELGIUM

A. Accidents

There are no official statistics kept specifically on grain industry fires and explosions in Belgium. Fire departments' statistics do record such incidents. The only major incident involved a fire at Ghent some seven years ago without any known causes.

B. Preventive Measures

This information is based on the measures employed by one of the largest silos and elevators in Belgium. Some of the safety features are as follows:

- Dust control. The elevators are well equipped with dust removal appliances.

- Avoidance of heat build-up that would accompany deteriorating or poorly stored grains.

C. Fire Fighting Equipment

Annual inspection of premises and equipment:

- The company contracts with one of a number of firms approved by the Labour Ministry for such inspections. A copy of the company's report is submitted to the Port Safety Committee and remedial action is taken where appropriate.

D. Elevator Design

The elevators are designed with fire and explosion prevention in mind. The principal method is through dust control. The entire installation is equipped with a dust aspiration or vacuum-cleaning system. The system provides for dust to be separated and returned to the grain stream rather than expelled into the air. Instead of explosion relief venting, the company has panelling and glazing at one end of the installation, both of which could give way in the event of an explosion.

The other design features are:

- no water in the silo top, hence no bursting pipes in the winter; and

- an extended earthing system subject to annual inspection and lightning conducting system subject to twice yearly inspection.

One kilogram of CO_2 per cubic meter in each silo is required by the fire department, which involves the installation of a CO_2 reservoir outside of silos to cover the capacity of the silo.

The company has been considering a central tube inside each silo, with a reserve of sand in a container near the base. The sand is kept in the container by a type of membrane which is designed to burst if temperatures become dangerous.

E. Special Safety Devices

The silos are equipped with temperature and moisture monitoring systems which provide readings at several levels within the silos. Machinery and other equipment are only protected by thermostats, fuses and the like.

F. Good Housekeeping

The company hired four full-time cleaners.

G. No Hand-Lamps:

Special 24-volt flood lights are provided but remain outside the silo and can be wheeled up to top side manhole covers on mobile cradles.

H. No smoking

I. Maintenance Control

No machine maintenance is carried out while elevators are in operation. No welding, soldering or metal cutting can be carried out until the silo has been shut down. If there is a "leak", it is temporarily patched with rubber and a silicone adhesive.

2.3 FRANCE

A. Accidents

In the following we shall list only those fires and explosions experienced by two companies. No comprehensive statistics on the incidents in France are available at the present.

a. Fire at a port grain elevator

Property damage alone of 20 million francs; this estimate does not include stored goods lost in fire or damaged by water. No casualties, but helicopter rescue performed.

Cause of the fire

Heavy rainfall, causing a considerable seepage of petroleum might have favoured a pocket of inflammable liquid near the receiving hopper, and the pocket caught fire, either by heating or from a spark. The entire site is said to be impregnated with petroleum as a result of the repeated dumping of adjoining storage tanks that took place during the last World War.

Observations

Fire protection measures were disregarded during the elevator's planning and construction.

Permanent fire fighting equipment was non-existent.

The location was only 30 metres away from a large petroleum storage area.

There was no static water supply at the site. Furthermore, the closest fire hydrant was 400 metres away.

b. Explosion at a corn elevator in 1976

Damage amounted to 20 million francs, but fortunately there were no casualties.

Cause of the explosion

The excessive amount of dust given off through the conveyor, and unusually intensive operation of the elevator (eight times its capacity) were reported as the cause.

B. Preventive Measures (Explosion)

Shelled corn should never be put into a storage elevator before being cleaned. If necessary, a separate buffer elevator should be used before cleaning. The receiving area for the corn and buffer elevator should be designated.

The cleaning building and the dryer should be more than 15 metres away from the main elevator. The dryer should not join any other building or facility.

In places where dust settles or where it is likely to infiltrate in the form of airborne particles, all potential causes of ignition as described before must be carefully kept out. The dryer, in particular, should not be located where such a risk exists.

The dust should be removed at its source with specially designed equipment.

All the dust should be routed directly to a fireproof compartment located outside the buildings and not adjoining any of them.

In areas of the facility where such a dust removal system is not suitable as, for example, elevators, screw or conveyors, cleaning and grading mechanisms and the like, all equipment must be enclosed in airtight metal covers to prevent dust in the air from entering, and each unit must have a magnetic device built into it so that bits of metal capable of producing sparks on impact are caught before the grain enters.

Dust exhaust system is to be designed to ensure a sufficient air exchange volume to maintain the dust concentration level below the minimum explosive limit at all times.

All the equipment should be designed to permit easy cleaning of residual dust. Roughness should be eliminated by means of suitable coatings and points, rounded inside corners, etc.

The ground under the conveyor belts should be made easily accessible, and should be such that it can be hosed down, or else washed by a constant stream of water during handling, covered with water or profusely soaked.

Maintaining the highest air humidity level that is compatible with the preservation, handling and use of the grain would further reduce the danger by raising the ignition temperature a little and by helping to eliminate electrostatic charges.

Expansion devices such as hatches, movable shutters and ruptured membranes should be provided to eliminate excessive air pressure created by possible explosions.

Lightning rods should be installed.

All wiring must conform fully to Union technique de l'électricité. Operations should be suspended when maintenance work is being done and during any alterations to the facility.

2.4 JAPAN

A. Accidents - Explosions (1962-1975)

Because Japan is a small, overpopulated country, an explosion accident in an urban district or at a port causes damage not only to a grain elevator or a processing plant itself, but also to surrounding buildings and even to people around. For the last several years, two to three dust explosion accidents occurred every year. This may be due to the great amount of grain dealt with in Japan. Most accidents occurred in the transportation process. In particular, at grain elevators, almost all accidents happened at transportation processes, such as elevators, conveyors and chutes. No accidents were initiated in dust collectors or separators. More than a half of all accidents were caused by sparks or melted particles in welding or cutting with torches in repairing. Fewer explosions than supposed were caused by electrostatic sparks. This may be due to the high humidity in Japan.

B. Preventive Measures

For most dusts, particularly agricultural dusts, it is almost impossible to use the rock dust or water which is used in coal mines to prevent dust explosions. Therefore, it is important to remove the causes of ignition. In Japan most caution has to be paid to welding and cutting works. It should be noted that the possibility of explosion accident is high not only when the elevator is out of full operation for some other trouble, but also at the beginning or the end of transportation in normal operation. In general, in order to prevent or reduce dust explosion accidents, it is recommended to reduce the oxygen concentration with inert gases, or to install a venting system properly.

Typical measures enforced at plant level in Japan for preventing grain dust explosion are as follows:

a. Dust control

Ducts are provided at the places where dust exists and bag-filter-dust-collectors are installed.

Machine rooms are constructed by steel-frame-slate board-finishing for easy sweeping.

Machine rooms are always swept because dust may accumulate so much, and ceilings, beams and walls are inspected and swept once a month.

b. Controlling fire ignition sources

Welding should not be done while machines are running. During welding, water is to be sprinkled around the area to prevent fire from spreading. Moreover the area around the welding flame is covered with some sheets of 2 inch anti-flaming sheet to protect inflammable substances against the fire.

No devices which may cause rubbing in conveyors and no electric lights other than explosion-proof electro types should be allowed.

Table 10

Dust Explosion Accidents by Cause of Ignition
(1962-1975), Japan

Cause of Ignition	No. of Accidents	%
Welding, Cutting	12	52.3
Impact	3	13.0
Electrostatic	2	8.7
Friction	2	8.7
Spontaneous Combustion	2	8.7
Overheat in Dryer	1	4.3
Unknown	1	4.3
TOTAL	23	100

Table 11

Explosion Accidents (1964-1975), Japan

Year	Material	Place or Process Explosion Occurred	Cause of Ignition	Fatality	Injured	Fire Induced
1964	feed grain (bran)	bin	unknown	0	2	no
1965	wheat	grinding	impact	1	0	no
1965	feed grain (barley)	grinding	friction	0	0	yes
1966	feed grain	bucket elevator	welding	2	11	no
1966	feed grain	grinding	welding	0	1	no
1966	feed grain	bucket elevator	welding	0	2	no
1967	rice bran	oil extraction plant	welding	2	6	yes
1968	feed grain	chute	welding	0	2	no
1969	skim milk	dryer	welding	0	4	yes
1969	wheat	bucket elevator	welding	0	3	yes
1969	wheat	bin	electrostatic spark	0	0	no
1971	soybean	chute	welding	0	7	yes
1972	copra	bin	electrostatic spark	0	0	no
1972	cornstarch	dryer	spontaneous combustion	0	0	no
1972	cornstarch	dryer	overheated	0	0	no
1973	feed grain (maize)	bin	welding	1	0	no
1973	feed grain (milo)	bucket elevator	friction	0	1	yes
1974	sunflower seed	grinding	impact	0	4	no
1974	feed grain	dust pipe	welding	0	0	yes
1974	feed grain	bucket elevator	impact	0	1	no
1975	feed grain	bin	welding	0	1	no
1975	soybean	dryer	spontaneous combustion	1	0	no
1975	rice bran	bucket elevator	cutting with torch	1	2	no
TOTAL				8	47	7

2.5 NETHERLANDS

The Dutch government claims that the safety measures in the country are generally superior to the standards of the American Occupational and Safety and Health Administration. In their experience, the human element is at the root of most industrial safety problems. In this regard, they hope eventually to eliminate casual and "grape-vine" training in the private grain handling industry, while admitting that the lack of training manuals is a serious problem. Aside from the ongoing process of educating management and labour, the inspectors pinpointed dust concentration and ignition sources as their major concerns.

A. Accidents

In the period 1971-1980, 59 cases of grain dust explosions were reported. In only 27 per cent of these cases the cause could not be identified, as compared to approximately 45 per cent unknown causes reported in other countries. This might indicate that in the course of time an ever-intensified search for the causes of a dust explosion was effective. As we shall notice from the following figures, the most important causes were welding and the use of hand lamp followed by friction and electrical spark. In the Netherlands the hopper and the bucket elevator are particularly hazardous, followed by the dust filter, the mixer, the drier and the conveying screw.

CHART 2

PERCENTAGE DISTRIBUTION OF REPORTED SOURCES OF IGNITION, NETHERLANDS

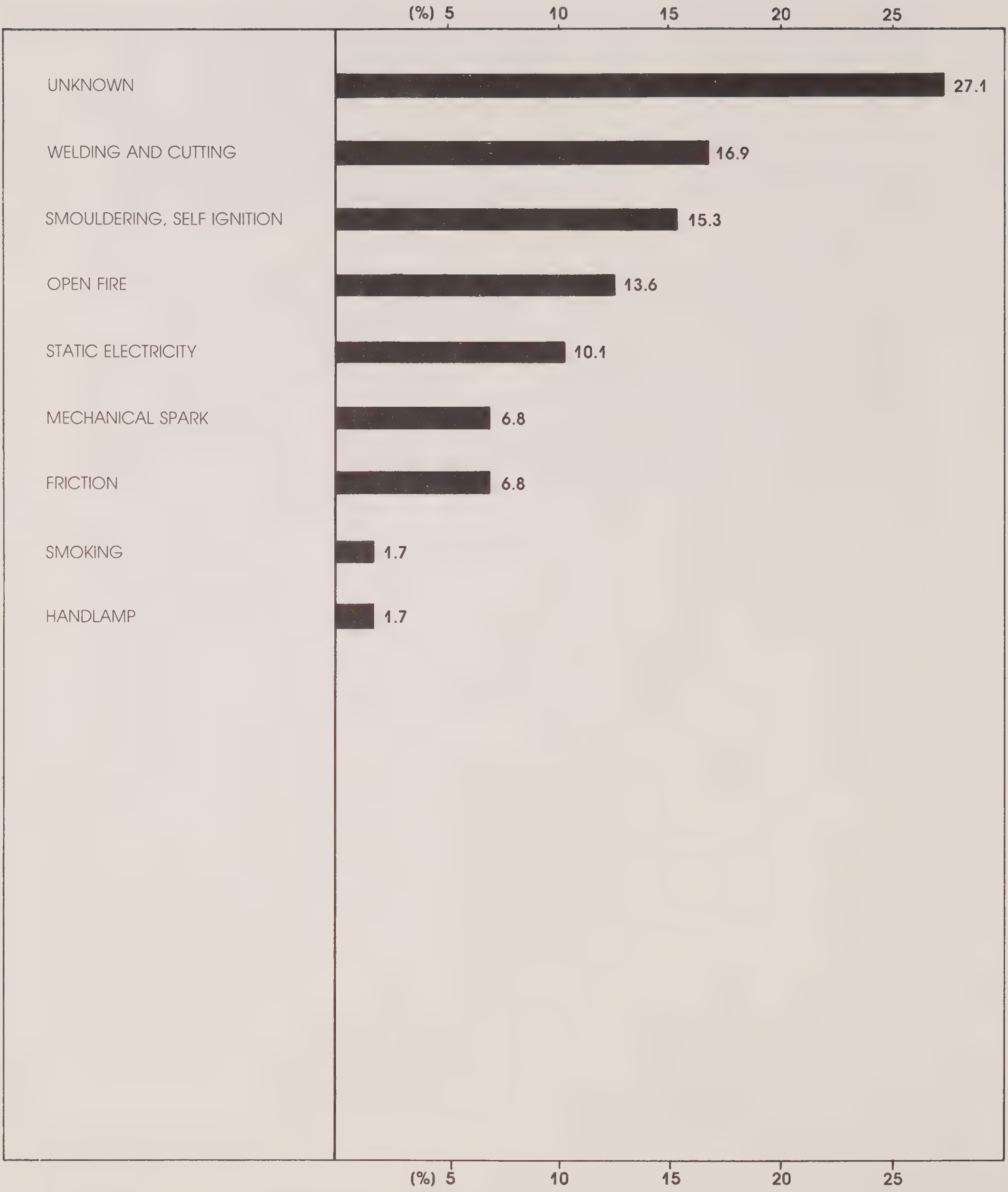


CHART 3

PERCENTAGE DISTRIBUTION OF EQUIPMENT INVOLVED
IN THE EXPLOSIONS, 1971-1980, NETHERLANDS

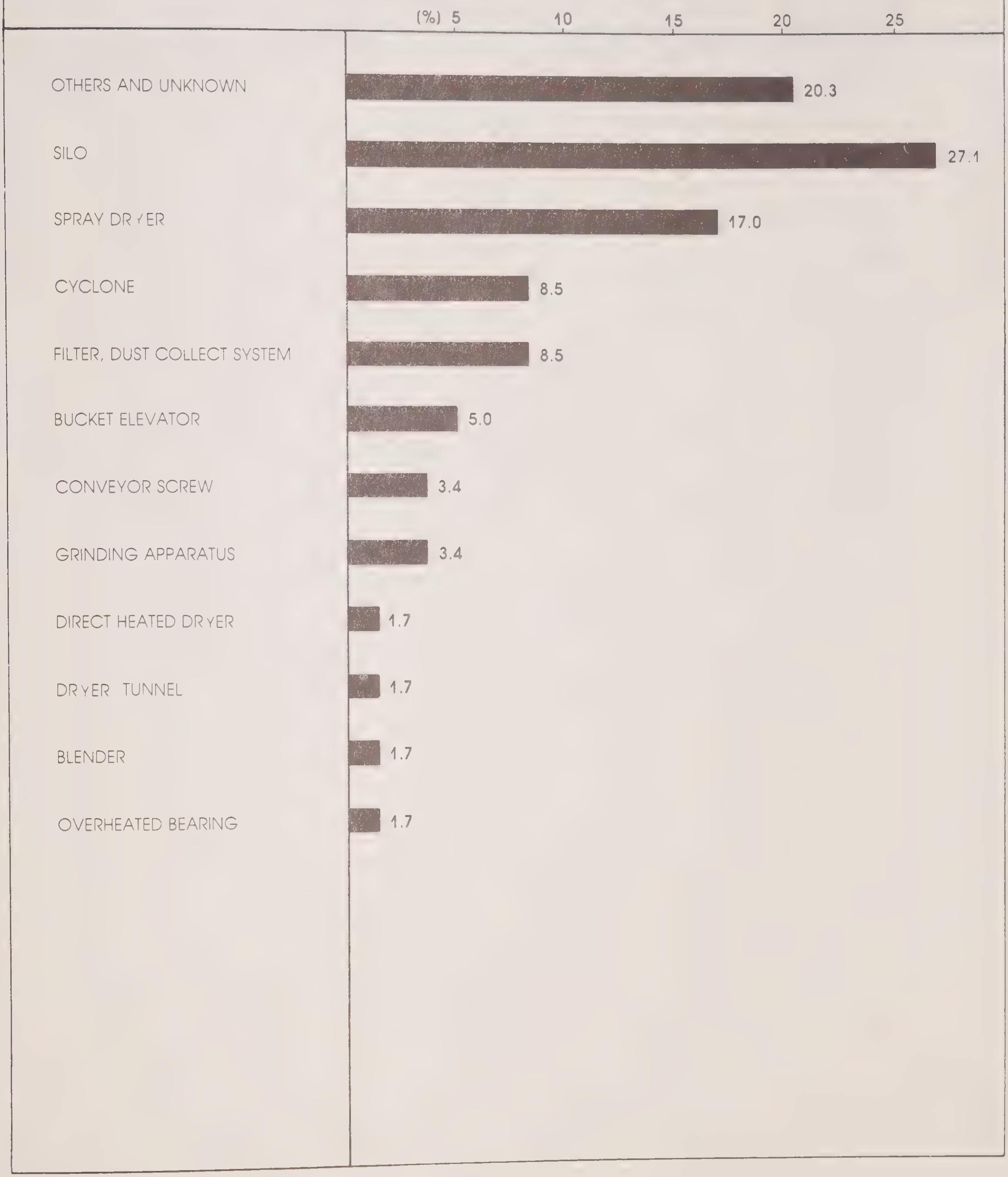


Table 12

Source of Ignition*, Netherlands

Sources of Ignition	No. of Explosions	Percentage
Welding and Cutting	10	16.9
Smouldering, Self-ignition	9	15.3
Open Fire	8	13.6
Static Electricity	6	10.1
Mechanical Spark	4	6.8
Friction	4	6.8
Smoking	1	1.7
Handlamp	1	1.7
Unknown	16	27.1
TOTAL	59	100.

*prins maurits laboratorium tno.

Table 13

Equipment Involved*, Netherlands

Equipment Involved	No. of Explosions	Percentage
Silo	16	27.1
Spray Drier	10	17
Cyclone	5	8.5
Filter, Dust Collect System	5	8.5
Bucket Elevator	3	5.0
Conveyor Screw	2	3.4
Grinding Apparatus	2	3.4
Direct Heated Drier	1	1.7
Drier Tunnel	1	1.7
Blender	1	1.7
Overheated Bearing	1	1.7
Others and Unknown	12	20.3
TOTAL	59	100.

*prins maurits laboratorium tno.

Table 14

Statistics: Dust Explosions (1971-1980) in the Netherlands

Year	Total No. of Dust Explosions	TYPE OF INDUSTRY					
		Dairy	Fodder Producing	Starch	Grain Handling	Wood	Others
1971	1			1			
1972	3		1	1	1		
1973	8		3	2		3	
1974	4	1	1			2	
1975	2				1	1	
1976	9		1		1	3	4
1977	8	1		3	1	1	2
1978	10	2	1		1	4	2
1979	4	1					3
1980	10	2	2			5	1

*prins maurits laboratorium tno.

Table 15

Number of Explosions By
Type of Industry*

Type of Industry	Total No. of Explosions Over 1971-1980	Percentage
Dairy	7	11.9
Fodder Producing	9	15.2
Starch	7	11.9
Grain Handling	5	8.5
Wood	19	32.2
Others	12	20.3
TOTAL	59	100.

*prins maurits laboratorium tno.

Table 16(a)

Data About Fodder Industry, 1979*, Netherlands

	No. of Workers Per Elevator		Total No.
	10-49	50	
No. of Elevators	146	56	202
No. of Workers	2 946	8 732	11 678

Table 16(b)

Data About Grain-handling Industry, 1981, Netherlands

Total No. of Grain-elevators (concrete)	11**
Total No. of Workers	unknown

*Only the larger import-elevators have been taken into account.

**prins maurits laboratorium tno.

B. Preventive Measures

- making all connections, inspection doors, slides and the like as dust-tight as possible and keeping them dust-tight, too, via an adequate maintenance scheme;

- where possible operating the equipment at a slight underpressure, so that no dust can escape from the inside to the outside;

- when enveloping the devices concerned, such as dumping hoppers in their housing or jacket, a slight underpressure should be provided for.

As regards the equipment the following can be remarked:

- It is desirable that hoppers and bunkers be closed so as to prevent the dust from escaping.

- With direct-fired driers it is important that the operations in the drying-room be restricted to filling and discharging.

- Starch, preferably, will be dumped under hoods of non-flammable material, which are sucked off so that as little dust as possible escapes.

- With driers it is important that the air-inlet be provided with a sieve so as to prevent husks, chaff, and the like from getting inside.

- Driers with direct heating shall be used only if the air required for the combustion passes through a filter.

- When designing driers, piping, etc., it must be taken into consideration that as little dust as possible should deposit on the structure.

- To prevent dust depositing outside a conveyor screw, it is important that it be accommodated in a well-closed jacket or housing.

- It is advisable to suck off cleaners and point removers (e.g., for oats) if they are not dust-tight.

C. Measures to Remove Dust

First and foremost every industry in this sector should have an adequate program for cleaning. It is important to regularly remove dust on floors and other surfaces during work. For this purpose use can be made of vacuum cleaners or a fixed vacuum cleaning system with hoses. In both cases, the suction chosen should be conductive and earthed via the suction system so as to prevent it from charging electrostatically. It is advisable to check the resistance of the hoses periodically. If a movable vacuum cleaner is used, it should be suitable for operation in a dusty environment. The motor should be closed, if it gives off sparks, so that it cannot form a source of ignition for the dust.

The dust should also be removed from places that are accessible with difficulty. The use of pressurized air for cleaning involves great risks. The dust is then not removed but whirled upward. In some cases, however, cleaning cannot be done otherwise. Sweeping with brooms must also be restricted as much as possible; they also whirl up dust. If it is necessary to use brooms for cleaning, then, preferably, soft ones should be used, as these whirl up less dust than hard brooms. In case of new constructions or modifications of an existing building, it is advisable to see that floors, ceilings, doors, and the like are smooth. Dust collectors should be installed at an isolated safe place.

D. The Occurrence of Sources of Ignition Outside the Equipment

In the following it is shown what measures can be taken to prevent, as much as possible, the occurrence of sources of ignition outside the equipment.

a) Welding and Cutting

A great number of dust explosions in the Netherlands were caused by welding. Therefore, we will stress that as much care as possible should be taken before, during and after welding.

- It is recommended that welding and cutting be implemented as much as possible in a workshop or another "non-explosion-dangerous" room.

- If welding or cutting in the machine building is unavoidable, it is recommended that these operations be allowed only after a written permit is issued by or in the name of the management.

This permit can state, among other items, the following:

- date of issue of the permit,
- place where the activities are carried out,
- date and time at which the activities are carried out,
- the nature of the activities,
- the safety measures,
- the name of the welder,
- the name of the supervisor.

The permit must in no case be of a general character and must be issued only when the functionary authorized to issue the permit has acquainted himself with the safety measures taken.
The safety measures specify:

- A certain period of time before welding is started, switch off the machines and devices in that section of the building where welding will be done.

- Clean thoroughly the machines at which welding operations will be carried out.

- Remove the dust within a radius of 10 m, as welding sparks may have a range of approximately 10 m.

- Remove inflammable material within this radius. Material that cannot be removed must be covered with fire-resistant blankets.

- Clean the floor of the storey below and wet both floors.

- In case of an automatic fire alarm installation, switch it off only at the location of the activities.

- During welding, do not switch off the sprinkler system, if present.

- Screen the sprinkler cap if welding will be done in its proximity.

It is important that during welding there be a man present with a fire extinguisher near the welder. Because of the welding goggles or welding mask, the welder has a limited field of vision, he is busy welding and, therefore, does not immediately observe the start of a fire. If there is the possibility that welding sparks will reach the stories above and below, fireguards with fire extinguishers should be present there too.

It is important to make a thorough inspection after the welding or cutting job. If welding sparks have landed in the dust, then it may

well take hours before a fire starts in it. Regular checks should be carried out for such a period of time that it is certain that there is no smouldering dust present any longer. The machines may be switched on only after the welded surfaces have cooled and an after check has been made.

Welding and cutting activities are often carried out by outside firms. Before they start work, they should possess the regulations in force at the appropriate factory.

This point must be normal practice, particularly if the outside firms work on the weekends. Then there should certainly be a fire duty guard who is employed by the firm.

b) Hand Lamp

Many of the dust explosions were caused by letting down a hand lamp into a hopper. Consequently, this must be advised against, as there is the risk of short-circuiting or ignition of dust by the hot lamp. Particularly risky is measuring the height of the material by letting the lamp down by the flex so far that it touches the material. Measurement can be done for example with a weighted rope in which knots have been made at every metre.

To illuminate hoppers internally, operators may use floodlights that have been mounted fixedly over the hopper or are running on rails; at any rate in such a manner that the lamp cannot fall down into the hopper. The cables of the lamp should be insulated adequately.

c) Open fire

In rooms where dust may be generated, no open fire must be allowed. At those places in the works where smoking may cause explosion risk, smoking should be prohibited.

d) Friction

By adequate maintenance and regular inspection the occurrence of friction can be prevented almost completely. In this respect the following items are important:

- Bearings ought to be lubricated with the prescribed grease.

- The axles of the various machines ought to be aligned correctly, to prevent bearings from overheating by friction.

- In case of devices being driven with the aid of V-ropes it should be ascertained that all V-ropes required are present. If one rope has to be replaced, all should be. This is in order to keep the tension of the ropes equal; the ropes should be made of anti-static material.

- Transport chains must not operate unloaded for any length of time.

  Bucket elevators and conveyors should be provided with slippage indicators, belt-lean indicators and abnormal running indicators.

- If a fire occurs in a hopper or bunker and it is to be emptied, it should be realized that a dust explosion may be generated if emptying generates much dust.

- As soon as a smell of smouldering is observed, the cause of which cannot be ascertained, the employees should immediately warn the foreman, so that the machines can be switched off until the cause has been found and the necessary measures have been taken.

e) Mechanical Spark

Before grinding is started it is desirable to remove the dust around the place where the work is to be done, to prevent the jet of sparks from landing in dust. As the jet of sparks goes in one direction, a spark screen can be used.

f) Static Electricity

To prevent electrostatic charges of metal parts, it is advisable to connect the metal parts with an electrical conductor and to ground them at one point. In this way spark discharge of the one part onto the other is prevented.

- It is desirable to check the grounding regularly, in particular after the construction has been completed, and after repairs.

- The grounding may be interrupted by plastic, by sealing of flange connections, films of greases, rust formation, contamination and the like.

- If static charges are formed on parts made of non-conductive material, such as driving ropes or rubber flaps, these parts can be replaced by anti-static rubber. Driving ropes and V-ropes can be provided with grounded cams.

- It is important that all metal objects in the proximity of non-conductive objects be grounded, otherwise induced charges on the metal object can become too high and hazardous.

- Static electricity should be removed by providing the elevators with grounded electric meters and other machines.

- The equipment for charging and discharging ought to be connected by an electric conductor and grounded. This includes the truck, bunker, connecting tube, motor, compressor, etc. It is important to ground the bulk truck before coupling to the tube. A chain

dragging behind the truck is not sufficient for grounding, as grounding quality depends on the humidity of the road surface.

The hoses ought to be reinforced, from coupling piece to coupling piece, so that they are conductive. It is advisable to check the resistance of the hoses periodically, especially after repairs.

- Various types of flour, in particular starch and starch products, can be charged electrostatically. This applies in general to types of flour that have an electric resistance of 10^9 Ohm or higher. Then the following measures can be taken to avoid the risk of electrostatic discharge:

  If the manufacturing process permits, do not dry the flour too far, and keep the air in the building sufficiently humid: When the relative humidity is raised to over 50 per cent; the discharge of the surfaces to a lower potential will proceed without damage; for this purpose use can be made of an air humidifier.

- In starch and dextrin factories it is important that the humidifier, if it is of metal, be well grounded. In particular when the charged powder is wetted, this quickly loses its charge at the wall of the equipment as a result of the increased conductivity. If the steel humidifier is not grounded, a high electric voltage at a great capacity can be obtained. To avoid this problem, wooden humidifiers are often utilized. In that case, strange as it seems, the water piping ought to be grounded.

g) Foreign Material

During transport or in fast-running machines, foreign material (stones, pieces of metal and the like) can give off sparks so that a glow fire is generated in the material to be processed. The glowing parts resulting from this process may ignite the dust present at another place (e.g., in the bunker), causing dust explosion. The following measures are of importance:

- Magnets to remove steel objects ought to be present for the first row of roller mills, for hammer mills and for other milling equipment;

- Magnets, permanent or electric, must be installed such that the material caught can adequately be removed;

- If electromagnets are used, the whole machine ought to be safeguarded against the falling out of action of the magnetic current, so the metal dropped by the magnet does not land in the machine, but is led to another place.

- If there is a great difference in density between the feed component and foreign material from which the component should be cleaned, a pneumatic separator can be used. A drawback of

this method is that the foreign material may be in touch with the dusty air, so that there may be dust explosion risk.

In modern starch factories stainless steel equipment and ducts are often used, while all bolts are also made of stainless steel. Loosened stainless steel bolts cannot be caught with a magnet. If it is powdered material a sieve can be used. For other materials (e.g., roller-dried materials in chipping form) a sieve cannot be applied. Then a pneumatic separator must be used.

E. The Prevention of Sources of Ignition in and by the Equipment

In most techniques in use in processing cereals and flour, much dust is generated in the equipment. This is part of the process and cannot be avoided. The only thing that can be done is to avoid as much as possible the ignition of the dust in the equipment. In the following, the measures to be taken to prevent the chief sources of ignition for the different machines and devices will be discussed.

a) Bucket Elevator

In both legs of an elevator much dust is generated by spillage from the buckets and by the flow of air in the legs. So here it is necessary to prevent the occurrence of a source of ignition.

In an elevator the most important source of ignition is friction, which results in a rise in temperature. The temperature can become so high that a fire can be produced, so that the dust generated explodes. Friction often occurs between the head pulley and the elevator belt, so that the belt can burn through and fall downward. Slipping of the elevator belt on the head pulley can be prevented by providing the elevator with an apparatus that stops the driving of the elevator if the belt is slowing down. For this purpose, e.g., a "speed watcher" can be mounted on the tail axle of the bucket elevator.

b) Grinding and Milling Apparatus

Grinding and milling equipment ought to be provided with magnetic separators, to ensure that no metal gets into the mills.

In particular, hammer mills ought to be inspected regularly and revised to prevent hammers or crusher plates from breaking as a result of wear. The debris might give off sparks and ignite the dust-air mixture.

c) Dust Filter-Exhaust System

The pipes of such an exhaust system ought to be well-grounded to prevent electrostatic charging. Flexible connections in the system ought to have a continuous earth connection, the resistance of which must not exceed 100 000 Ohms.

d) Direct-fired Furnaces

It is important to provide driers with equipment that prevents the material to be dried from glowing or burning during the process. This can, for example, be attained by application of automatic temperature regulators and/or thermostats that automatically cut off the heat supply in case of too high a temperature in the drier.

Driers, piping, etc., should be designed in such a way that the surface temperatures remain so low that deposited dust does not start glowing.

It is advisable to regularly inspect and purify driers in which oily material is normally dried. In fact, a slight layer of oil forms at the inner side of the drier and at elevated temperature this oil can easily ignite spontaneously.

It is desirable that the material coming from the driers be adequately cooled before it is stored in the hoppers. If the material is stored too hot, the change of spontaneous heating and self-ignition increases.

e) Ventilation System

If the product being processed tends to stick to the rotor and the housing, it is advisable to clean these parts periodically to prevent friction and a rise in temperature.

If axial ventilators are applied for a dust-air flow, they have to meet the requirements for a dust-explosion-hazardous environment.

It is advisable to cool the motors of an axial ventilator indirectly.

f) Conveyor Screw

It is not advisable to have conveyor screws and chain transporters operating in unloaded condition for a long time. The material left behind is then rubbed for some considerable time and, because of the increase in temperature, it can come to self-ignition.

g) Lighting

Sources of lighting ought to be dust-tight. This applies to filament lamps, fluorescent lamps and sodium vapour lamps.

Filament lamps and sodium vapour lamps without housings are dangerous, because dust can deposit on them and, owing to the high surface temperature of the lamps, the dust can start glowing. Fluorescent lamps ought to be covered, because, when started, induction sparks are generated that might ignite the dust-air mixture. This holds for sodium vapour lamps, too.

Filament lamps, and also sodium vapour lamps, may be mounted against a ceiling or wall if these consist of non-flammable material such as concrete or stone. Otherwise it is advisable to keep mountings a distance of at least 20 mm. from ceilings or walls.

h) Electric Installation

It is advisable to accommodate electric gear as much as possible in dust-free rooms, such as control rooms and cabinets or boxes. To keep them dust-free, they may be kept under over-pressure with filtered atmospheric air. If electric equipment must be present in dusty rooms, it is important to place it so that no dust can enter it; for this purpose the devices can be placed in a housing. The surface temperature of that housing ought to remain at such a low level that no deposited dust can start glowing.

When installing electric gear in explosion-hazardous rooms, standard NEN 1010 ought to be reckoned with. It is emphasized, however, that this standard concerns measures that have to be taken to prevent gas explosions. It does not apply straightaway to the prevention of dust explosions.

i) Cleaner

In the case of cleaners and pointers, metals must be caught, e.g., with the aid of magnets. Stones ought to be removed, too.

F. Measures to Reduce the Effect or the Extension of a Dust Explosion

The cover of the hopper ought to be constructed of as light material as possible, as ought the roof over it. If a dust explosion occurs, the cover and possibly the roof will be flung off and away.

It is desirable to mount dry filters with housings in a separate room. This room ought to be constructed so that, in the event of an explosion, the outer wall can be flung away and the explosion cannot move through the machine building.

Open filters without housings should preferably not be utilized. If they are damaged by an explosion pressure, the filter bursts open, so that a great amount of dust can be generated that can bring about a subsequent explosion by the flame front of the dust explosion.

It is better to suck off the machines separately rather than to make use of a central exhaust system. In case of a central system there is the risk that an explosion will continue in all directions as a result of the many connections.

G. Fire

It is essential that a continuing program be worked out for fire and explosion prevention, with co-operation between management and employees. The implementation of such a program should always be checked by a safety officer. It is advisable that the program comprise instruction for new employees in which their attention is drawn to the dangers, how they can avoid them, what measures they must take and how they should use the pertinent equipment, such as fire extinguishers. Regularly conducted brush-up courses on hazard prevention are advisable.

The temperature inside the grain elevator should be constantly checked by using the electronic thermometer attached to it; and the temperature of the running parts of the machine should be recorded on a temperature-indicating tape. Fire alarm, extinguisher, hydrants and hoses, etc., should be placed on every floor.

Fire fighting teams should be organized and carry out regular inspection and patrol.

It is important to check fire extinguishers and other precautionary measures periodically.

The staff should know where the fire extinguishers are. In case of a fire the following steps should be taken:

1. Switch off sections as soon as possible.

2. Avoid whirling up of dust as much as possible; therefore do not spray into dust with a concentrated water jet; if dust burns cover first with carbonic acid.

3. After extinguishing, check after an adequate period of time; to ensure complete extinguishing has occured.

4. Only switch sections on again if there is a firm conviction that all danger has gone.

2.6 SOUTH AFRICA

Grain production in South Africa is concentrated on a plateau, the Highveld, lying just south of the Tropic of Capricorn. There are about 200 grain elevators on the Highveld.

A. Accidents

We know of only three minor explosions: these took place in bucket elevators and were caused either by bearings running hot or by welding accidents. South Africa has been so free of dust accidents that the subject has not until now received particular attention.

B. Preventive Measures

Most of the elevators are modern in design. The typical elevators consist of free standing concrete bins 15 m in diameter with semi-hopper bottoms and reclaim tunnels. The workhouse is normally constructed of bins 7.5 m in diameter clad with sheeting. Gantries are now built with grating floors but many of the older elevators have fully enclosed gantries.

The elevators are essentially storage installations, i.e., they are seldom filled more than once during a harvesting season. Working spaces are well ventilated. Reclaim tunnels are equipped with high capacity extraction fans and consequently ambient atmospheric conditions are probably present in the workhouse spaces.

Maize and wheat are accepted straight from the combine harvesters and, while pre-cleaners are now commonly used, maize is still stored "dirty" in many elevators and cleaned on reclaim. Wheat has always been cleaned before delivery to the bins.

Intake capacities are relatively low - about 150 t/h per conveyor belt with matched bucket elevators and other machinery. Usually two or three sets of machinery are used providing capacities of from 300 to 450 t/h.

Conveyor belts are used far more than chain conveyors and to date only steel buckets have been used on bucket elevators; fibreglass buckets are now being considered.

2.7 SWEDEN

A. Accidents

The national Swedish Board of Occupational Safety and Health knows of only one dust explosion during elevator handling of grain and feed in Sweden during the past five years. This explosion, which occurred in a feed storage silo, did not cause any personal injuries. As far as the Board is able to assess, fire safety and electrical safety requirements are well catered to in agricultural buildings. Effective exhaustion devices are customarily installed for the handling and storage of grain. Probably, therefore, the lower explosion threshold is seldom exceeded. The dust contained in the exhausted mixture of air and dust is separated off in subsequent filters. Afterwards this fine grain dust is usually used in the manufacture of livestock feed.

Two large fires involving fatalities and extensive material damage have occurred in large silo facilities during the past few years. There have been several known instances of grain bins failing because they have been inadequately constructed, and fatalities have also occurred in this connection. The Board is currently represented in a study group which has been set up to deal with various problems, including those connected with dimensioning.

There have been several cases of farmer's lung in connection with the handling of mouldy grain. The most striking instance of this kind occurred at a school of agriculture, when an instructor and ten or more students were hospitalized. In another case the resultant lung damage was of such a kind as to demand artificial lung treatment.

Accidents of other kinds have occurred in the agricultural sector in connection with the storage and distribution of grain.

B. Preventive Measures Against Grain Dust Explosion

1. Elevators must be dust-proof or sufficiently enclosed to prevent dust escaping from them while they are in operation, or else they must be provided with efficient exhaust arrangements. Hoppers, etc., involving unnecessary accumulations of dust are to be avoided. Furthermore, an elevator must be positioned and enclosed in such a way as to minimize the transmission of dust between premises linked by the device. Enclosure should be carried out using non-flammable material or at least an anti-ignition covering.

2. Elevators must be provided with explosion venting areas. This requirement can be dispensed with, however, if the machine is designed to withstand the pressure of explosion, or if it is so positioned that a dust explosion will not be liable to injure personnel.

3. Elevators must be provided with suitably positioned cleaning and inspection hatches.

4. Elevators must be constructed and installed in such a way that they are readily accessible for purposes of maintenance, inspection and cleaning. They must be constantly supervised and they must be kept in good condition.

5. Elevators must be constructed and installed in such a way as to minimize the danger of an outbreak and of spread of fire.

6. Elevators must be fitted with a cut-out device positioned in such a way that they can easily be stopped if there is a danger of fire or explosion occurring. The main exit from a facility should also be fitted with a device for turning off all the machines, fans, etc., in the installation.

7. The accumulation of static electricity is to be prevented by connecting the conducting parts of the elevator tower equipotentially and grounding them with a cable or wire at least 16 mm^2 in cross-sectional area.

2.8 USSR

At present about 1 000 elevators are being operated all over the country.

A. Accidents

It is reported simply that "recent dust explosions in grain elevators causing serious health hazards and human losses attracted special attention of administrative and trade union organizations".

a) Causes

Ignition sources may be divided into two groups, "occasional" and "organized". Occasional ignitions include short circuits in wiring, self-ignition of different materials, overheating generated by friction of machine parts, lightning, discharge of static electricity, and impact of solid articles. Organized ignition sources are: electric and gas welding, electrical heaters, non-protected lamp fittings, smoking, use of torches and other causes. The second group of ignition sources constitutes 40 per cent of all causes. One of the most hazardous explosion causes in silo bins is self-ignition of products.

B. Preventive Measures

Reducing the explosions caused by the first group (occasional) may be achieved by means of a number of volumetric-planning designs; as follows:

- removing of a cable from the areas where explosions may occur;
- installation of an automatic signalling system recording heating of rubbed parts of machinery;
- arrangement of a lightning protection system;
- grounding of static electricity;
- usage of materials which do not generate sparks in the facilities when impacts are possible.

Elimination of the second group of causes may be achieved by training workers.

Investigations of explosions have revealed that the more elevator volumes are connected, the more destruction may occur.

To protect grain elevators from explosions and fires, organizational and technical measures provided by building standards and fire safety provisions are being taken. Structural parts of buildings should be of fireproof materials. Automatic valves should be arranged in the openings of fireproof walls for conveying belts.

To minimize repair work inside elevator buildings, facilities for disassembly of bearing members should be provided for spouts and protective casings. This will facilitate their delivery to a repair shop.

Welding is prohibited when the equipment to be welded is in operation.

Provision is made for introducing a system to warn operators of explosive conditions. The system will ensure the installation of sensors to control dust accumulations in processing rooms, heat sensors to detect potential ignition sources, regulation of temperature in separate parts of technological equipment, or sensors responding to the availability of carbon monoxide and signalling potential ignition or self-ignition of grain and dust deposits.

Dust should be stored in bins placed outside of processing rooms and silo bins.

Studies are under way on the possibility of dividing the elevator volume into a number of isolated volumes with independent releasing of blasts into the atmosphere.

Thus, measures for protecting grain elevators from dust explosions have the following features:

- Design of effective explosion-discharge installations in machinery and equipment;

- An aspiration system against dust in workplace facilities;

- Measures to localize explosions in the smallest possible volume of the building;

- Sieve separators to separate dust from grain when it freely falls into different bins and silo bins.

2.9 UNITED KINGDOM

The table below indicates the scale of grain handling and distribution in the United Kingdom in millions of tonnes.

	Imported Grain	Home Grown Grain
1976/77	8.9	10.9
1975/76	8.4	11.6
1974/75	7.1	13.1

Each 12-month period commences at July. The largest grain storage installation in the United Kingdom has a capacity of 180 000 tonnes.

a) Explosion Accident Experience
(Information about Northern Ireland is not included.)

According to the records for the years 1958-1977 there has been only one explosion in this country in premises solely concerned with grain handling and storage; this was a bucket elevator explosion in 1959 caused apparently by a lead lamp getting into the bucket elevator; there was no silo or secondary explosion in this incident and, it would seem, no injuries.

During the same 20-year period there were nine explosions and three fires in grain handling equipment at other premises. In only one of these, a maltings, was a secondary dust explosion produced by a fire and there were no silo explosions at any of the premises. Four of the explosions occurred in food mills, two in distilleries and one in a flour mill; two of the fires were in feed mills and the other was in a maltings (which was not the one which suffered an explosion).

The maltings explosion injured two men; two of the other explosions, one in a distillery the other in a feed mill, were caused by welding on bucket elevators and injured five men; there were no injuries or fatalities in the other explosions or fires.

Table 17

Accidents (Great Britain, exclusive of Northern Ireland) 1958-1977

Explosion or Fire	Frequency	Place or Process	Cause	Fatality	Injured
Explosion	1	grain handling or storage	lead lamp	0	0
Explosion	4	feed mills	one explosion caused by welding	0)))	5
Explosion	2	distilleries	welding on bucket elevators	0)	0
Explosion	1	flour mill	unknown	0	0
Secondary dust explosion produced by fire	1	maltings	unknown	0 0	2 0
Explosion	1	other grain handling equipment	unknown	0	0
Fires	2	feed mills	unknown	0	0
Fire	1	maltings	unknown	0	0

B. The Application of Precautions

Based on this experience the risk of a dust explosion in a grain handling and storage plant has been considered somewhat remote, and the attitude has been adopted that modification to provide explosion relief on existing plants used solely for grain cannot be justified. But it is recommended that explosion relief should be fitted on new plants. In addition major emphasis is placed on the need to avoid accumulations of dust within confined spaces when storing and handling grain. It is recommended that both new and existing large dust collectors associated with grain handling and storage should be suitably fitted with explosion relief.

So far as electrical equipment is concerned, it is simply recommended that where it is exposed to flammable dust it should be dust-tight, but there is at present no specifications for such apparatus. However, the British Standards Institution is developing such specifications, which will be used with an area classification concept.

It is possible the resulting standard will be akin to the US standards referred to in the US government Hazard Alert of January 5, 1978.

C. Legal Requirements

There are no specific legal requirements directed at preventing explosion in grain storage and distribution. However, these activities are subject to the general requirements of the Health and Safety at Work, etc., Act, 1974, which obliges every employer to ensure, so far as is reasonably practicable, the safety at work of all his or her employees (Section 2) and the safety of all persons not in his or her employment who may be put at risk by the working activity (Section 3). Section 6 of the same Act places duties on those who design, manufacture, import or supply plant in connection with work activities and on erectors and installers to ensure that it is safe when properly used so far as is reasonably practicable.

The general impression concerning this topic, explosions, is that whilst we cannot exclude the possibility of a major dust explosion in grain storage in this country the risk is considerably lower than in the US where the hazard has been recognized and the precautions known for many years.

D. Health Hazards

Farmer's lung is the most common industrial disease caused by dust in agriculture in Great Britain. This allergy usually occurs as a result of handling dusty hay, straw or corn whilst feeding and bedding down livestock, or milling and mixing their rations. As for fumigation hazards, however, they are able to associate only one reported gassing incident since 1975 with the fumigation of grain elevators; this was non-fatal and the fumigant involved was phosphine. Other possible health hazards, not referred to in the OSHA document, include disease caused by grain metabolites (including chest disease) and the danger of vitiation of the environment and carbon dioxide intoxication.

The general duties of the Health and Safety at Work Act oblige employers to ensure the health and welfare, as well as safety, of their employees, as far as is reasonably practicable. This includes such things as the provision of adequate lighting, dust control and washing facilities. Health and Safety Inspectors regularly advise farmers and others on the dangers to health, as well as of explosion, of working in dusty conditions. Similar precautions are recommended for both purposes; to keep dust releases to a minimum, to clear away regularly all dust deposits, and where necessary to install means of extracting dust from the air, etc. There are no regulations requiring employees working in dusty conditions involving vegetable material to wear respiratory protection, but they are always advised to use dust respirators designed to British Standard BS 2091 with a "B" type filter. This standard of protection reduces the risk of infection from farmer's lung disease.

In the years 1958-1977 there has been only one explosion in grain handling and storage, and nine explosions and three fires in grain handling equipment at other premises, with no fatality.

E. Preventive Measures

Although the probability of a dust cloud being exposed to a source of ignition can be minimized by good design, it cannot be reduced to zero. Hence methods of explosion protection must be considered.

The principal methods are:

- minimizing cloud formation,
- containment,
- separation of units,
- relief venting,
- inerting,
- automatic suppression.

a) Minimizing Cloud Formation

Where a large bin or silo is being filled, it is better for the dust not to fall freely from a high point but to be introduced gently, preferably at various openings in the side.

A silo should not be used as a dust separator in a pneumatic conveyor system. The separation should be done separately in a cyclone or other suitable unit, and the dust fed gently to the silo. Plant units should not be so much too large for the process, that they never become filled to the design level, leaving large volumes which can contain dust suspensions. Where exhaust ventilation is provided, the dust should be removed from the air as soon as possible, and not be transferred over long distance to control separators.

b) Containment

The principal of containment is that the plant is sufficiently strongly built so that it can withstand the maximum explosion pressure without damage. With grain, this would be as much as 7 bar (45 kg/cm^2). The method of containment is only likely to be attractive in a plant of small dimensions and would not be practicable on grain elevators.

c) Separation of Units

If hazardous plant units can be separated from each other, then, in the event of explosion, a domino effect can be avoided. With grain elevators the various units, such as conveyors and bins, must of necessity be in close proximity so that the principle of separation is not readily applied. Separation of buildings containing people from hazardous plant is often possible and has not in the past always been given full consideration. With tall plant structures, control rooms and

other populated buildings should be spaced laterally along the plant separated by distance at least equal to the height of the plant.

d) Relief Venting

The principle of relief venting is the provision of apertures in the plant or building so that if an explosion occurs, and the internal pressure starts to rise, the increase is limited to a predetermined value which is related to the strength of the structure. The maximum pressure obtained depends on the area of the vents and on their distribution. Wherever possible, vents should be situated near where the source of ignition is likely to be, and on large plants multiple vents are required.

Information is available on the area of vent required (NTPA 1974; Palmer 1977). The NTPA publication deals with the venting of dust explosions inside vessels and is directly relevant to storage bins and silos, and dust collectors associated with grain elevators. The publication is based directly on experiments in vessels up to 60 m^3 (2 100 ft^3) volume but extrapolation is needed for a larger volume. There is a lack of direct information but for large elongated bins (of height/ diameter ratio up to six) there is some merit in requiring half the area of the top of the bins as vent (Palmer 1977).

In bucket elevator legs there is likely to be a dust cloud, due to the movement of the buckets, and ignition from friction or impact can occur. Explosion vents equal in area to the cross-section of the leg should be provided at the head and the boot and, if the leg is more than 12 m (40 ft) long, at 6 m intervals in the casing. The legs should be mounted outside the building. A similar distribution of vents is desirable on conveyors where, although dust may not be permanently in suspension, sufficient may be present within the structure to enable a secondary explosion to develop and to sweep the entire length of the conveyor with increasing violence unless checked by explosion protection measures.

As the action of a relief vent is to expel flame and burning dust, strict attention to the safe disposal of explosion products must be made. They should be directed away from populated areas or vulnerable neighbouring plant. It is undesirable for explosion vents to deliver their discharge into the interior of buildings.

e) Inerting

If inert gas is permanently introduced, during normal work, into dust handling plant then the oxygen concentration can be lowered sufficiently so that explosion will not occur even though a source of ignition may be present. The gases used are frequently nitrogen or carbon dioxide. In general, the method is unsuitable for use on grain elevators because of the large volumes involved, the need to provide accurate monitoring of gas compositions at numerous points, and the requirement for an inert gas supply of adequate capacity. Inerting is usually attractive when either the atmosphere in the plant can be recycled with minimal loss or generous supplies of inert gas are freely

available as a by-product. In the case of grain elevators this is not the case, and inerting is only likely to be attractive for special application in specific relatively small units.

f) Automatic Suppression

When a dust cloud becomes ignited the flame initially moves relatively slowly and the incipient rise in pressure can be detected rapidly so that a suppression agent can be injected into the volume to quench the flame before it raises the pressure to a hazardous level. Commercial systems are available and may be attractive for at least parts of grain elevators, e.g., elevator legs. Installation of the systems requires expert knowledge and is commissioned from the commercial supplier.

In considering the explosion protection of grain elevators, it has become clear that adequate safety cannot be obtained by either attempting to eliminate sources of ignition or by avoiding the presence of dust. Neither requirement can be met fully because both aspects will arise during normal working, but the design of the elevators should as far as possible reduce the likelihood of sources of ignition and dust being present. However, good design in this respect can give only partial protection. For full protection additional measures must be taken and that which is most generally applicable is likely to be relief venting.

For units on the elevator complex which are designed to collect dust, such as filters and cyclones, the venting requirements have been given straightforward coverage (NMPA 1974). In meeting the requirement of the code, attention must be paid to the design of the vent cover, and the need to ensure that flame and combustion products discharged from the vent do not endanger personnel or neighbouring plant. Advice on both aspects is given in the code.

The parts of the elevator complex concerned with the transport and storage of grain need particular consideration. In these parts, the dust that arises from the grain is the most likely explosion hazard, rather than the grain itself, which is of relatively large particle size. During the operation of the elevator the grain dust may either be in suspension, as in a bucket elevator due to the movement of the buckets, or may have settled out but be vulnerable to disturbance, as in conveyors. In both bucket elevators and conveyors, an explosion may propagate throughout the length, either because the dust clouds are present or because the explosion can generate it. Both bucket elevators and conveyors should therefore be protected with vents over their entire length. As a general rule, one vent every 6 m (20 ft) is desirable, equal in area to the cross-section of the bucket elevator or the conveyor. Such generous venting is particularly desirable where the bucket elevator and conveyor casings are of square or rectangular section, rather than circular, as they will then be structurally weaker. The amount of venting specified is designed to keep explosion pressures,

under the worst conditions, down to 0.15 bar (0.9 kg/cm^2) and the casings to the bucket elevators and conveyors should be capable of withstanding this pressure.

In the provision of relief venting generally, and with elevators and conveyors in particular, it is important that all parts of the cross-section of the units have access to the vent, so that the explosion may be relieved without internal obstruction. Some consideration of explosion venting requirements is given in the NFPA Standard for grain elevators (NFPA 1973). Although a relatively large amount of venting is required for the protection of bucket elevators and conveyors, a greater number of smaller vents, distributed evenly and to the same total area, may be used instead. The smaller vents may be particularly applicable when existing plant is to be modified; with new designs the larger vents may be more economical.

Conveyors which run underground present a particularly difficult problem. Relief venting to atmosphere is essential, and it cannot be to the bins or silos. In existing installations, access to the outside air may have to be provided specially for the vents; in new installations access should be designed in the first considerations. If venting is not provided for underground conveyors the pressure of explosion may be sufficient to dislodge and damage the overlying bins or silos, thus leading to catastrophic loss. Grain elevators with underground conveyors not fitted with venting thus present a difficult problem, which needs to be considered on an individual basis.

Bins and silos should be vented at their tops. Difficulty may arise in providing adequate access to the atmosphere of vented flame and combustion products. The venting requirements of the silos may then need to be considered together with those of the conveyor. At the present state of knowledge for large volumes, the area of the vent should not be less than half the area of the top of the bin or silo, and preferably larger, particularly if the bin or silo is of non-circular cross-section, and structurally weak. With circular sections, design strengths of 0.15 bar (0.9 kg/cm^2) should be obtainable without difficulty, but other geometries may present problems. If bucket elevators and conveyors are adequately vented, so that explosion does not damage their structure, then protection of the bins and silos against serious structural damage is obtainable. However, if bucket elevators and conveyors are not adequately vented then the bins and silos are also put at risk.

Because elevators are tall structures, burning material vented at high level can fall out over a wide area, depending on wind conditions. As a general guide, horizontal spread could be at least as far as the height of the structure. Similar considerations apply to vent covers, which may be dislodged and escape from their restraint. Buildings housing personnel, including control rooms, should preferably be outside the area of fall out. If it is not possible to site the buildings at an appropriate distance, then special strengthening measures, particularly of roofs, may be necessary.

The result of an explosion in a grain elevator, even if it is adequately vented, may be a sustained fire. Such a fire may well be severe because of the size of the explosion flame which initiated it. Fire fighting on this scale requires trained personnel, who will also need protection against smoke and fumes. Untrained personnel should be discouraged from participating.

F. Fires in Dust

Unlike dust explosions there are two types of burning in dust fires, flaming and smouldering. The type of burning depends on the characteristics of the dust, the dimensions of the deposit, and the ease of access of air. With flaming the rate of heat release is likely to be higher than with smouldering. If a suitable ignition source is present the burning of dust layers with flame can take place provided the quantity of dust is sufficient, it is distributed favourably, and the supply of air is adequate. Whether a particular dust can burn with flame so as to present a fire hazard may need to be determined by tests because it cannot be predicted reliably. Relatively little information is available on the burning rates of dust layers and until the theory of flame propagation over layers is developed, recourse must be made to experiment for information on burning characteristics. However, the sources of ignition which give rise to dust fires are the same as those for dust explosions, and the precautions to be taken are similar.

Two types of smouldering can be distinguished. In the first type the smouldering propagates over the surface of the dust deposit, or, if the deposit is thin, the smouldering burns practically the full thickness. The second type is ignition within the deposit, the smouldering propagating through the dust, mainly upwards until it reaches the surface. Propagation across the surface then proceeds as with the first type. Propagation through the deposit is usually the result of the buried ignition source, or ignition on a hot surface. Some information is available on the smouldering rates, and the effect of air flow, and on the transition to flaming (Palmer 1973).

There are no special types of fire detector designed solely for use against dust fires. When the dust is burning with flame it may well be emitting heat, light and smoke. Detectors are available which are sensitive to these emissions, but difficulty frequently arises because of interference by dust entering the detector. False alarms may then be a problem.

Automatic sprinkler systems fulfil the dual purpose of detecting fire and attacking it. They can give protection against fires in dust providing the heat output from the fire is sufficient to activate the sprinklers. This requirement would usually mean that the dust was burning with flame and that the sprinkler heads were directly accessible to the products of combustion of the fire.

If the dust is smouldering the rate of burning is usually slow, hence the heat release is also slow. The quantity of smoke pro-

duced varies with the nature of the dust, and reliable detection can be very difficult.

Fire detection systems do not have sufficiently rapid response to enable them to give warning of explosion. In addition, they may be rendered unserviceable by the effects of explosion, so that the fire fighting function of sprinklers may be lost.

Fires in dusts may be extinguished either by allowing the fire to burn all the dust, or by applying extinguishing agents, or by treating the dust deposit so as to exclude oxygen from the fire. Whichever method is used great care should be taken to avoid disturbing the dust into a cloud because burning material is present and may cause an explosion.

Allowing the fire to burn itself out may be possible for small amounts of dust but is not likely to be generally acceptable. If the method is used, continuous watch must be kept at all stages to ensure that changes in burning can be dealt with. Such changes are likely to arise from sudden air draughts, the burning away of the dust below its surface, and the failure of structures under the action of heat.

The usual approach is to extinguish the fire. Selection of the most suitable agent depends on factors such as the amount and situation of the dust, and the presence of nearby equipment. The extinguishing agent most commonly used for grain is water, which should be applied from a low pressure spray, and not from a high pressure jet. The action of high pressure water could be to disperse the dust into the air thus giving rise to an explosion hazard. If the dust layer is one metre or more in thickness, water applied as a spray may not penetrate into the mass of the dust. The dust must not then be vigorously stirred, but either it should be gently removed by digging and the spray application continued, or the use of a wetting agent in the water may be tried. Because of the necessity of applying water gently and of ensuring that it penetrates into the dust, extinguishing fires with water can be slow. Fire fighting foams, dry chemicals, or vaporizing liquids, as fire fighting agents, would have a limited use in the present context.

Gases or liquefied gases may be used as extinguishing agents provided that disturbance of the dust is avoided. Their action is basically the exclusion of air; hence their effectiveness as extinguishing agents depends upon their being present for a sufficient time to allow the dust to cool sufficiently to prevent reignition when the dust is again exposed to air. The agents will thus be particularly effective for a dust which is contained within a relatively gastight volume, e.g., a bin or silo. The agents have the advantage that they are able to penetrate relatively easily into the dust and can be used in fighting fires in large volumes. However, in such large volumes the heat insulation is good so that natural cooling of the dust is very slow. To ensure complete extinguishing of the dust fire the gas must be maintained for long periods, possibly for days or weeks. Liquefied gas should be introduced to the dust through piping which should penetrate into the dust so that the cooling effect as the liquid boils can then contribute to removing heat from the fire. Gas introduced in liquid form is likely

to be an effective extinguishing agent, but a close approach to the fire may be needed by operatives in setting up the system.

There is scope for further research into improved methods of applying extinguishing agents to fires in grain, paying particular attention to the large amount of material which may be burning, and to difficulty of access.

2.10 UNITED STATES OF AMERICA

There are about 15 000 grain storage and handling facilities in the United States, employing 225 000 workers. Approximately 10 000 of these facilities are grain elevators, and the rest are feed mills, flour mills, and other grain processing plants. Out of the 10 000 grain elevators, approximately 80 are export terminal elevators with over half of these elevators operating on a year-round basis. The other grain elevators, i.e., country elevators, operate seasonally with a work force that fluctuates, many part-time employees being used during the harvest season which is the peak employment period. During these peak employment periods, many grain elevators operate 24 hours per day.

A. Accidents

Grain elevator dust explosions averaged about 6.7 per year from 1938 to 1946. Then the average fell to about two per year from 1947 to 1955 and increased to about eight per year from 1958 to 1975. Since 1976, the number of explosions and fires in grain elevators has increased significantly. The recent series of explosions and fires, in which more than 60 persons were killed and many more injured, has elicited serious concern about the health and safety conditions of persons employed in the grain industry. Grain elevators rank first in industrial explosions; that is, in regard to the number of occurrences, the number of people injured and the amount of property damaged. Five times as many occur in grain elevators as occur in the flour and starch industries and more than 1.5 times as many as in the feed and cereal mills. Grain elevator fires are almost 500 times more numerous than grain dust explosions. Over 29 000 fires occurred between 1964 and 1974 and this resulted in an average of approximately 2 900 fires per year. Many more fires may not have been reported. The following table shows figures for explosion incidences in grain elevators and feed mills from 1958 to 1978.

Table 18

Explosion Incidents in Grain Elevators and Feed Mills, 1958-1978, U.S.A

Year	Number of Incidents		Deaths	Injuries
	Elevator	Feed Mills		
1958	8	2	2	27
1959	8	2	3	18
1960	8	4	4	18
1961	8	2	0	17
1962	8	1	3	51
1963	8	6	3	30
1964	2	6	3	22
1965	6	3	2	5
1966	9	5	2	22
1967	12	5	1	14
1968	9	7	12	38
1969	1	5	4	13
1970	10	0	1	14
1971	9	1	4	14
1972	2	6	7	23
1973	6	2	2	10
1974	10	5	13	37
1975	6	3	4	19
1976	18	4	22	82
1977	13	8	65	84
1978	7	5	7	47
Total	168	82	164	605

Source: U.S. Department of Agriculture, "Prevention of Dust Explosions in Grain Elevators - An Achievable Goal", draft report, Washington, April 1979; taken from Table 2 - 1.

The trend for the period 1964 through 1973 showed a yearly number of fires as follows:

Table 19

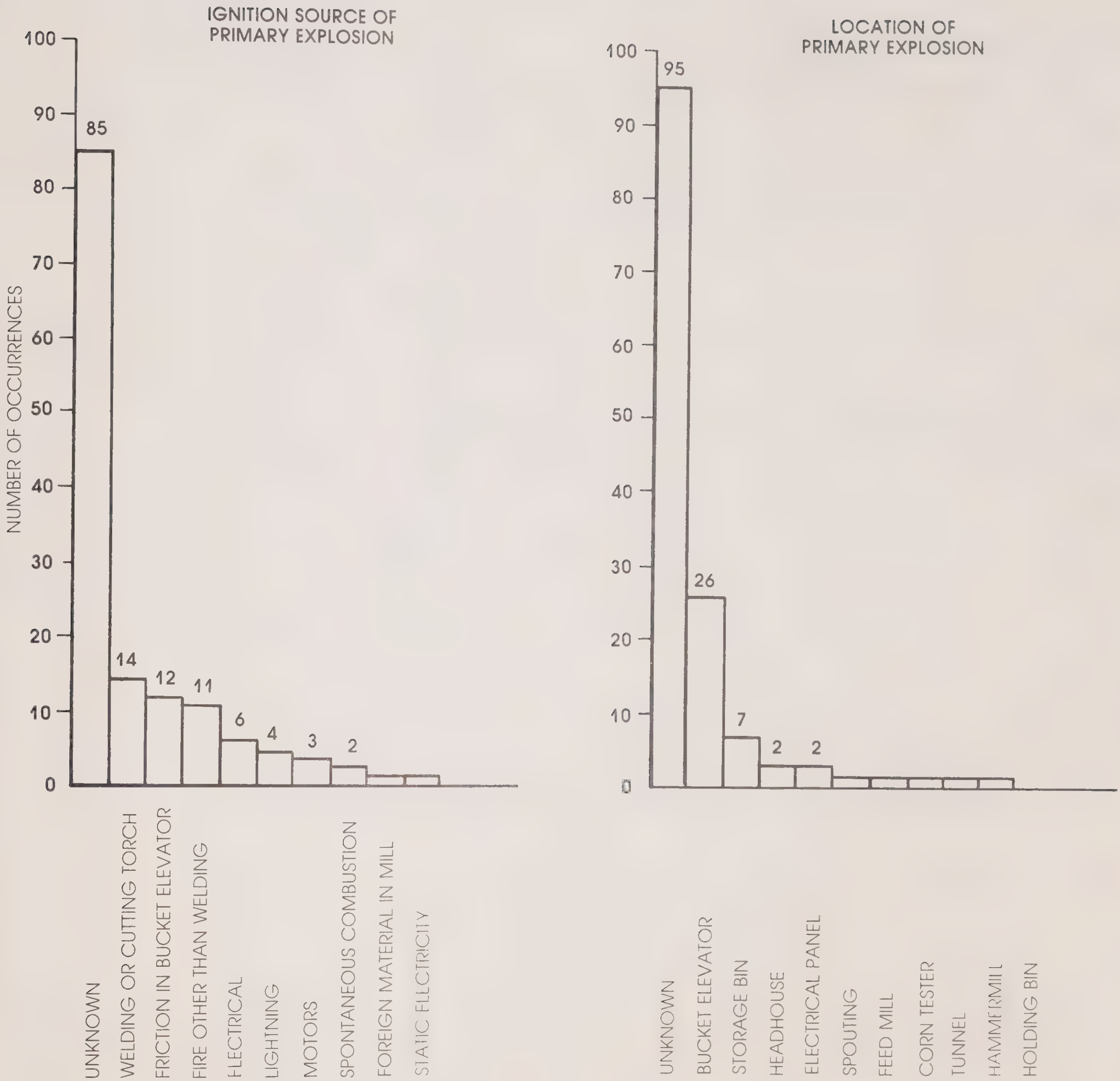
Fires and Property Losses, U.S.A.

Year	No. of fires	Property loss
		$
1964	2 000	29 500 000
1965	1 900	22 000 000
1966	2 000	23 000 000
1967	3 000	26 200 000
1968	5 300	26 600 000
1969	4 700	26 700 000
1970	3 000	47 800 000
1971	3 100	49 800 000
1972	2 400	42 800 000
1973	1 800	39 300 000

A significant decrease in the number of grain elevator fires per year has occurred since the peak years of 1968 and 1969. This may have resulted from an increasing use of fire protection equipment such as automatic detection and alarm systems and sprinkler installations.

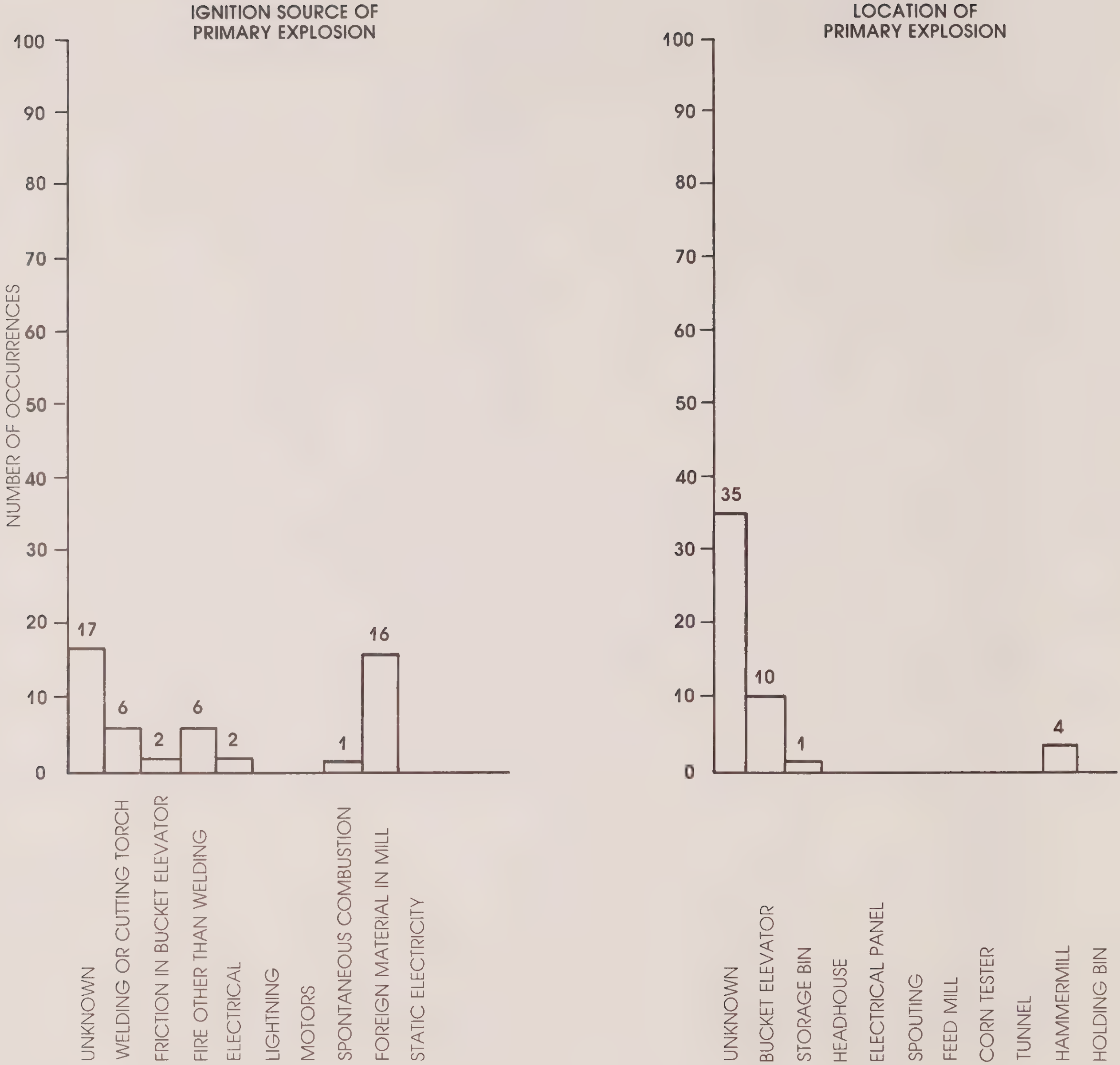
Charts 4 and 5 indicate the frequency with which the identified causes have resulted in explosions in grain elevators and feed mills from 1958 through 1975 along with the location of the primary explosion when known.

CHART 4



Causes of U.S. grain elevator dust explosions and location of primary explosion, 1958 through 1975
(From Table 2 of this report)

CHART 5



Causes of U.S. feed mill dust explosions and location of primary explosion, 1958 through 1975. (From Table 3 of this report)

B. Prevention and Control of Grain Elevator Explosions

Many of the means of explosion prevention and control in grain elevators have similarly been repeated frequently. These recommendations include:

1. prevent escape of dust from equipment by making it dust-tight and providing a permanent dust collecting system operated at a slight negative pressure;

2. minimize dust accumulations by use of smooth walls and floors, minimum horizontal surfaces, inaccessible surfaces inclined at a 60° angle, and placement of equipment to facilitate cleaning;

3. strictly enforce no smoking rules;

4. strictly supervise and control welding, cutting and soldering operations;

5. use only electrical motors, switches, fuse boxes, wiring and light fixtures which conform to the NFPA Electrical Code for Class II, Group "G" specifications;

6. place magnetic and pneumatic separators ahead of machinery;

7. prohibit shoes with nails in plant;

8. avoid aluminum, magnesium and similar light metal paints in elevator;

9. ground all electrical motors, dust collectors, ducts, metal bins, etc.;

10. clean and examine magnetic separators regularly and often;

11. use battery operated lamps instead of electrical ones on leads for inspecting bins;

12. never lower metal objects into bins;

13. provide lightning and surge voltage protection;

14. maintain proper tension on belt of bucket elevators; use anti-run-back devices; inspect regularly and frequently for loose bolts and loose or bent cups; keep strut board under head pulley free of dust and grain accumulations; assure proper clearance between elevator casing and pulleys, belt, and cups; provide all elevator legs with automatic mechanical or electro-mechancial devices to shut off all driving power and sound an alarm if the belt slows down or stops while the head pulley continues to turn;

15. provide adequate explosion relief venting on buildings, bucket elevators, bins, and conveyor galleries;

16. educate employees with regard to dust explosion hazards and prevention;

17. lubricate bearings regularly according to manufacturer's directions;

18. assure proper alignment and maintenance of belt drives; avoid V-belt drives wherever possible;

19. use an inspection report form to ensure regular maintenance;

20. use only Underwriters' Laboratories approved chemicals such as fumigants;

21. use hot water or low pressure steam heating; locate the boiler or steam generator in a separated and isolated room which is constructed of fire-resistive material and is free of dust or other combustibles;

22. separate hazardous operations by suitable screw or rotary chokes;

23. where possible, use equipment designed to contain an explosion;

24. provide as large a space as possible between sections of the elevator;

25. clean up accidental accumulations of dust promptly and regularly; do not use compressed air for removing dust; use vacuum dust removal systems instead of push brooms.

It is difficult to determine to what extent any of these recommendations are currently implemented in grain elevators. A survey of grain elevators in Iowa and surrounding states would be useful. It would be especially valuable to know to what extent they had been followed in elevators which experienced grain dust explosions in the last two decades. Such a study would best be undertaken by the industry itself, perhaps through the offices of their grain and feed associations, to assure maximum co-operation and to avoid the inquiry being viewed as an adversary proceeding -- a tendency which appears to be widespread throughout our society today.

A 1972 survey of 175 commercial grain elevators (a statistical sampling of the 7979 US grain elevators) included 104 country elevators with a total storage capacity of 101 903 000 bu., 48 inland terminal elevators with 336 904 000 bu. storage capacity, and 23 port terminal elevators with a storage capacity of 118 547 000 bu. This survey revealed that 28 per cent had active dust control programs compared to 20 per cent the previous year. Whether or not this represented a true

increase is not clear, because 15 per cent of those who responded in the 1971 survey did not do so in the 1972 study. The largest decrease in those responding occurred among the country elevators. It is also this class of elevator which indicated proportionately much less involvement in dust control. In 1972, dust control systems were reported by 15.4 per cent of the country elevators, 37.5 per cent of the inland terminal elevators and 65.2 per cent of the port terminal elevators. Plans to install dust collecting systems were reported by 20 per cent of all the elevators. These included 12.5 per cent of the country elevators, 39.6 per cent of the inland terminal elevators, and 13.0 per cent of the port terminal elevators. No plans to install dust control were reported by 52 per cent of all the elevators which returned the questionnaire in 1972. These included 72.1 per cent of the country elevators, 22.9 per cent of the inland terminal elevators, and 21.7 per cent of the port terminal elevators. Articles appearing in the technical and trade literature have called dust collection the first line of defense against fires and explosions, and have outlined requirements for an efficient system.

No smoking signs are frequently posted in grain elevators but enforcement may not be uniform. Insurance companies distribute these free of charge to their insured accounts and will generally check to see that they are posted.

From the relatively frequent and recent cases in which welding or cutting operations have been cited as causes of explosions, it would appear that not enough is being done in this area. Insurance companies produce free literature, instructions, and posters describing the hazards and procedures to be followed. The trade literature has also published instructions for these operations.

Breakdown of electrical equipment was noted to be the leading cause of fires (not explosions) in grain handling and processing plants every year from 1945 to 1970. Only about one-fifth of these were due to motor bearing failures. Motor failures were due to dust accumulation, overfusing, lack of maintenance on controllers, and voltage surges.

Though not explicitly linked to dust explosion ignitions, these observations would tend to suggest that more attention should be given to this problem. Substandard wiring, motors, light fixtures, fuse boxes, etc., are frequently cited by Iowa Occupational Safety and Health inspectors.

Installation of magnetic separators appears to be fairly common practice, but problems have been encountered due to lack of regular maintenance. Heavy accumulations of tramp metal in magnetic separators have been cited in several grain dust explosions during the past two decades.

A device can be adequately protected from excess amperage via proper fuses or circuit breakers, but these are not very effective for voltage surges. It was noted in 1970 that the National Electric Code had not given sufficient attention to surge voltage protection. Less than half of grain handling and processing plants were so equipped in 1970. The cost is said to be "small".

There appears to have been no specific design effort to provide adequate explosion relief venting. Large window areas are often provided in bin top conveyor galleries. However, it was observed during a personal inspection of the September 25, 1975, explosion at Lincoln, Nebraska, that in many cases the sash did not open and many of the panes were broken. Earlier studies would indicate that very high pressures may have been required to break the glass thus negating any explosion relief effect which might have been provided by the sash.

The Iowa Grain and Feed Association in co-operation with Kansas State University conducts annual Grain and Feed Mill Operations Workshops in four locations around the state of Iowa for managers and employees. Kansas State University personnel began conducting these workshops in their state in 1963. A significant portion of the workshop deals with fire and explosion hazards. Dust explosion demonstrations, films and slides, and distribution of the booklet, Prevention of Fires and Dust Explosions in Feed Mills, Flour Mills, and Grain Elevators are included in the workshop.

Copies of the slide presentation and audio tape cassette narration may be purchased from Kansas State University. The insurance industry sponsors safety education for its clients and will provide, on request, materials and speakers. The annual Governor's Safety Conference in Iowa included a one-day session on Grain and Feed Mill Safety. In addition IOSHA has sponsored Grain and Feed Mill Safety Seminars in five locations around the state, and offers IOSHA Safety Regulations Update sessions through the Iowa community college system.

Safety education is the responsibility of management, and the need for persistent attention to this area is heightened by the frequent use of temporary inexperienced help. The dust explosion demonstration employed by the Kansas State University personnel could easily be duplicated by any manager with inexpensive materials and could help to dispel the skepticism, especially among young workers, that grain dust can explode.

Maintenance in general appears to be an often neglected task especially during peak operation, and it is frequently then that it is most necessary. Jim Peterson, Safety Engineer for the Iowa Grain and Feed Insurance Company, notes that bearings equipped with overheat alarms need to receive more careful maintenance than those not so equipped. Instructions for proper bearing maintenance have appeared in the trade literature. In 1970, all "major" elevators of the Peavey Company, an interstate grain firm, were reportedly installing fire warning systems in which overheated motors or bearings activate an outside alarm. At about the same time two co-op elevators in North

Dakota installed fire detection and dry pipe sprinkler systems. The detectors were located in all electric motors and wherever bearings were located. In addition to an outside siren and an inside horn, a signal box in the main office indicated the specific location of the problem. Reductions in insurance premiums as a result of this installation were expected to pay for the system in seven to eight years. An active campaign by the Farmers Elevator Mutual Insurance Company of Des Moines, Iowa, has resulted in the installation of dry pipe sprinkler systems and automatic alarm systems in about 200 of their insured elevators since January 1, 1973.

It was noted in 1967 that the most important improvements being made in grain elevators and feed mills included surge voltage protection, automatic fire alarms, and dry pipe sprinkler systems for the headhouse. To prevent chokes and overloading of motors, interlocking control systems for machinery, instantaneous trip relays to automatically control the flow of stock, and bin level controls were being installed.

C. Other Approaches to Explosion Protection

a) Inert Atmospheres

An industrial representative, in 1960, was interested in determining the possible market for inert atmosphere systems for grain and seed storage. The potential benefits of this method were said to be fourfold:

(1) reduction of grain spoilage due to oxidation and aerobic bacteria;

(2) control of sprouting;

(3) inhibition of insects, rodents, and other pests; and

(4) reduction of fire hazards.

Responses from several large grain firms stated that (1) the main interest in inert atmosphere storage would be the inhibition of insects, rodents, and other pests because spoilage and sprouting are adequately controlled by reducing the moisture content of the grain; (2) a considerable amount of experimental work had been done but the results were inconclusive; and (3) costs would be prohibitive due to difficulties in providing airtight storage; concrete is porous and allows exchange of gases through the walls; iron clad buildings cannot be pressurized; and existing steel tanks have openings for ventilating, filling, and discharging grain; modification of the latter would be too expensive. No further details were available.

b) Explosion Suppression

Explosion suppression systems, capable of extinguishing an explosion within milliseconds of ignition, are commercially available.

They are employed extensively in starch industries in Europe and have been installed in a number of these plants in the USA.

c) Polyvinyl Chloride Components

The use of polyvinyl chloride (PVC) belting in bucket elevators is being explored as a means of decreasing the flammability of the belt, which is usually constructed of rubber impregnated fiber. However, tests conducted by the Bureau of Mines indicate that the flammability characteristics of PVC belting are comparable to those of rubber. To eliminate friction sparks caused by metal buckets hitting the elevator leg casing, the use of PVC buckets is also being investigated. However, PVC may present an even greater hazard to personnel and buildings. When heated to 200°C, PVC decomposes to yield a considerable amount of hydrogen chloride (HCl), a toxic and corrosive gas. Corrosion of metal equipment and structural members is reportedly visible within three days. HCl also combines with the lime in plaster and concrete to form $CaCl_2$. The latter is a persistent corrosive agent which seeps deep into walls and attacks structural steel members embedded in the concrete. An instance was cited in which damage initially estimated at about $2 000 was later adjusted to $4 000 000 after this hidden damage was discovered.

d) Dust Control

Complete containment of dust in conveying systems and storage vessels is one of the principle methods for reducing the dust explosion hazard. This is usually attempted by applying a slight negative pressure to bucket elevators and by placing systems over open belt conveyors, particularly at transfer points, to remove floating dust. The effectiveness of these techniques is less than complete and accumulations of dust on walls, ceiling, and equipment is likely. One large interstate grain firm has taken a different approach to dust control. Their newer installations, built in the late 1960s and early 1970s, incorporated a completely enclosed, dust-tight conveyor system, which they designed. The building is operated at a slight positive pressure by means of a 3 hp ventilating fan to prevent escape of the dust from the conveyors should an accidental leak occur. After six years of operation, it was reported that a general cleaning had not been necessary in the entire time. A black cloth wiped across the walls was said to show no indication of dust accumulation. Furthermore, the use of conventional electrical wiring and fixtures was approved by the municipal inspector and the insurance company. Open wiring, standard fuse boxes, switches, etc., and fluorescent lighting fixtures appreciably reduced construction costs. Additional advantages of the new, high capacity conveyor system were said to be low initial cost, complete elimination of conventional dust collection equipment, power economy, less space requirements, no spillage, greater adaptability to remote control, and lower overall building costs. Their newer installations are remotely operated from a central control room. Although conversion of existing structures to accommodate these innovations may be impractical, planning of new elevators could well benefit from these techniques.

e) Implementation and Enforcement of Preventive Measures

The insurance industry, through monetary incentives, provides an effective means for implementing explosion protection measures. By allowing premium discounts in return for installation of preventive measures, grain elevators can thus be encouraged to provide the necessary precautions.

As noted previously, codes for the grain handling industry were among the first to be formulated by the NFPA and date back to the 1920s. Current NFPA codes include standards for the prevention of fire and dust explosion hazards in starch manufacturing and handling, grain elevators, feed mills, sugar and cocoa manufacturing, spice grinding, and confectionary plants. Of these, only the codes for sugar and cocoa plants and for spice grinding have been incorporated into OSHA. The National Institute of Safety and Health, US Department of Health, Education and Welfare, include in their Health and Safety Guidelines for Grain Mills the following requirements relevant to dust explosion hazards:

(1) no smoking rules must be posted and enforced;

(2) good housekeeping practices must be followed;

(3) non-spark shoes and tools should be used;

(4) explosion-proof light sockets and switches must be installed;

(5) proper fire extinguishers must be provided;

(6) welding or cutting operations must not be permitted where combustible dusts are present; and

(7) procedures for welding and cutting operations must be formulated. However, under the general duty clause of the Williams-Steiger Act of 1970, which established OSHA and NIOSH, hazardous conditions or practices not encompassed explicitly in the standards adopted by OSHA legislation are also covered. In Iowa, enforcement of OSHA requirements is the responsibility of the Iowa Bureau of Labour as a result of legislation which established the Iowa Occupational Safety and Health Administration (IOSHA). The Bureau has a total of 15 industrial inspectors to oversee all of Iowa's industries including approximately 1 500 grain elevators.

The NFPA Standard for the Prevention of Fire and Dust Explosions in Grain Elevators and Bulk Handling Facilities, which has not been explicitly adopted by OSHA includes the following as absolute requirements:

1. Construction materials must be non-combustible or fire resistive.

2. Automatically closing fire doors must be provided in fire walls.

3. There must be no openings between bins (directions for venting bins are outlined).

4. Explosion relief venting must be provided in accordance with NFPA Standard No. 68, including elevator legs, dust collectors and ducts, and pneumatic conveyor systems.

5. Elevator legs must be constructed of non-combustible material, dust-tight, provided with sample inspection and maintenance access, and driven by individual motors and drives of optimum size.

6. All machines must have individual connections to the power source and not run idle.

7. Magnetic, pneumatic, or other separators must be placed ahead of grain processing machinery to remove all foreign material larger than the size of the grain being processed.

8. Belt drives must have a sufficient service factor to stall driving forces without slipping.

9. Screw conveyors must be fully enclosed.

10. Roller or ball antifriction bearings must be used. Lubrication inlets must be provided with dust caps.

11. Spouts must be dust-tight.

12. The code includes a lengthy list of requirements for installation, operation, and maintenance of driers.

13. A dust collection system conforming to NFPA Standards No. 91 and 66 must be installed at all dust producing points including boot pits, automatic scales, scale hoppers, belt loaders, belt discharge, trippers, distributor heads, at the end of belts, and on cleaners, scalpers, etc., if they are not dust-tight.

14. Static dust, spills and chokes must be immediately removed.

15. Electric equipment must conform to NFPA Standard No. 70, Articles 500 and 502.

16. Heating systems must be approved for Class II locations.

17. Smoking must be prohibited.

18. Machinery and conveyors must be grounded in accordance with NFPA Standard No. 77.

19. Procedures required for welding or cutting operations must include written permission; shut down of machinery and dust-producing operations prior to, concurrent with, and following these operations until final inspection has been made; cleaning and wetting down of floors and surroundings and the area below the site of welding; floors and wall openings tightly sealed; and inspection and patrol of the area for a sufficient time following these operations.

20. Power operated tools must not be used in a dusty environment.

RECOMMENDATION:

To better assess the magnitude of the existing problem of dust explosions and fires in the Canadian grain industry, it is essential that a more comprehensive centralized reporting system of all such incidents, regardless of their severity, be set up. To do this, it must be established that all concerned components of the grain industry be required to report to a central collection agency.

Present data collection is piece-meal, done by different agencies in various areas. Because fewer incidents occur within each reporting sample, the apparent gravity of the dust explosion and fire situation is devalued. Amassing of the facts by one centralized agency to produce an aggregation of data will produce statistics with more weight and authority, and will thus increase awareness within the industry of the problem and of the need for preventive measures.

One of the serious drawbacks of the present fragmented method of reporting is the lack of representability that results from small samples; the larger reporting sample that would be a product of centralized reporting would yield data with greater representability, permitting more accurate extrapolation of causes, and other accident parameters.

For these reasons, it is strongly recommended that responsibility and authority be given to one centralized agency for the collection of data in a standardized format on dust explosions and fire in the grain industry.

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